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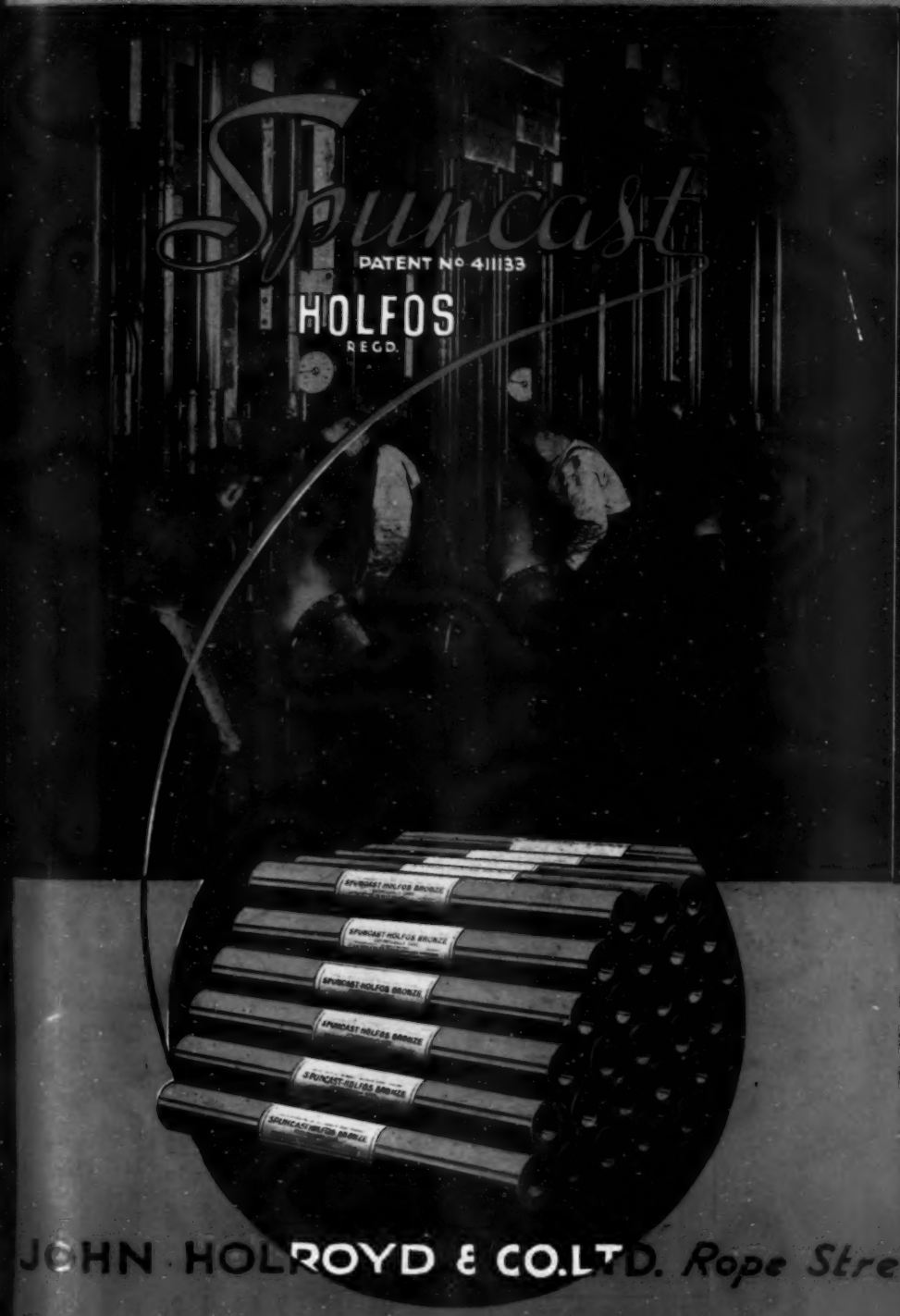

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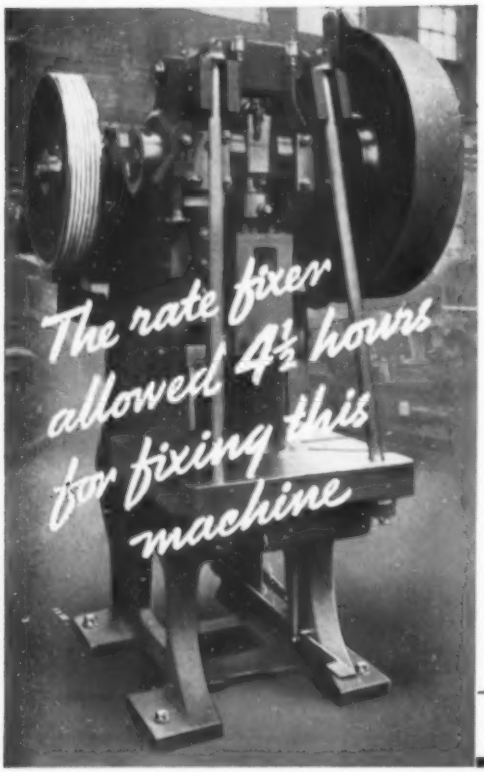

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The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

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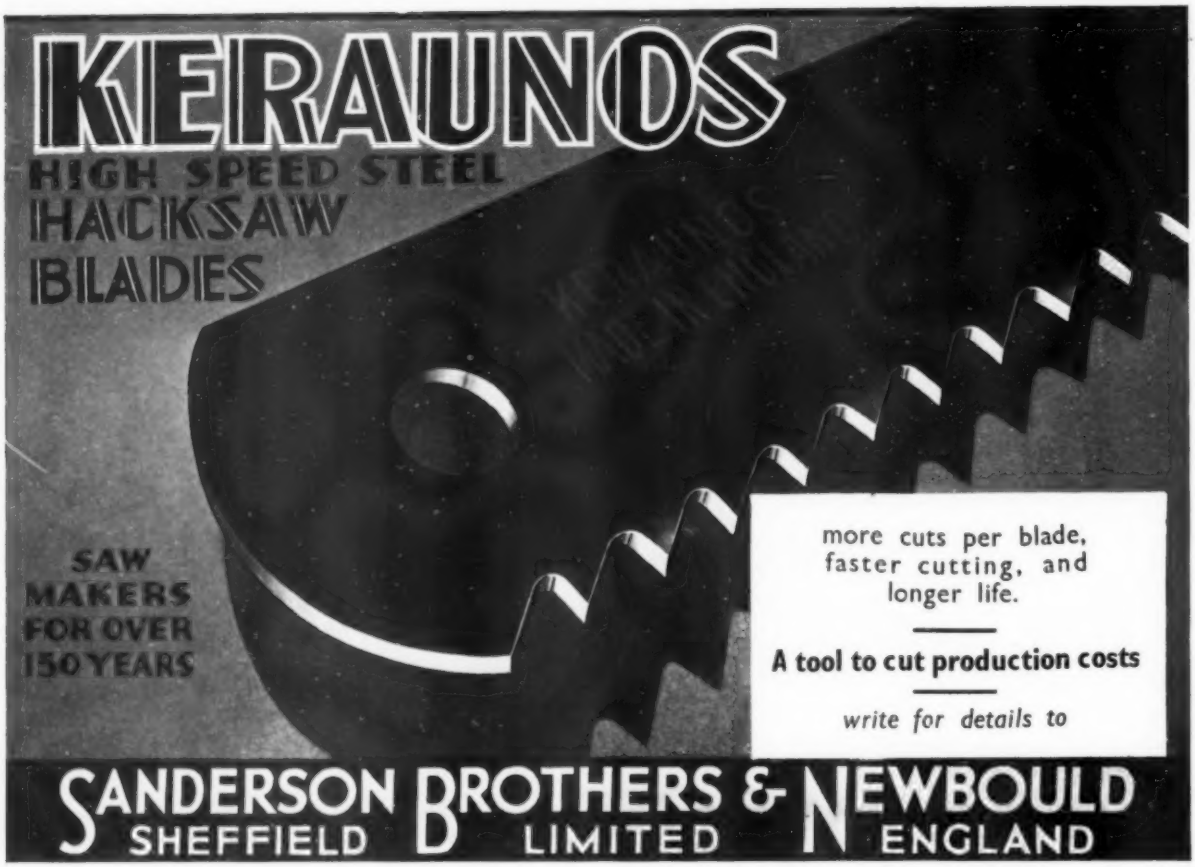
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THE BRITISH JOURNAL OF METALS.
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MAY, 1940. VOL. XXII, No. 127.

The New Laboratories of High Duty Alloys, Ltd.

Advances in scientific achievement and their application to the production and utilisation of materials have been accompanied by striking developments, and the research laboratory assumes more and more the position of the most essential aid to further advances. This is particularly true of the light metal industry, the progress of which is probably without parallel in metallurgical history. The value of research in this field has been recognised by High Duty Alloys, Ltd., since the inception of the company, and these new laboratories, recently officially opened by Sir Henry Tizard, show the importance with which it is regarded. This general description will indicate the steps being taken to meet the ever-increasing demands of the engineer for light alloy components possessing special properties and capable of meeting more stringent requirements.

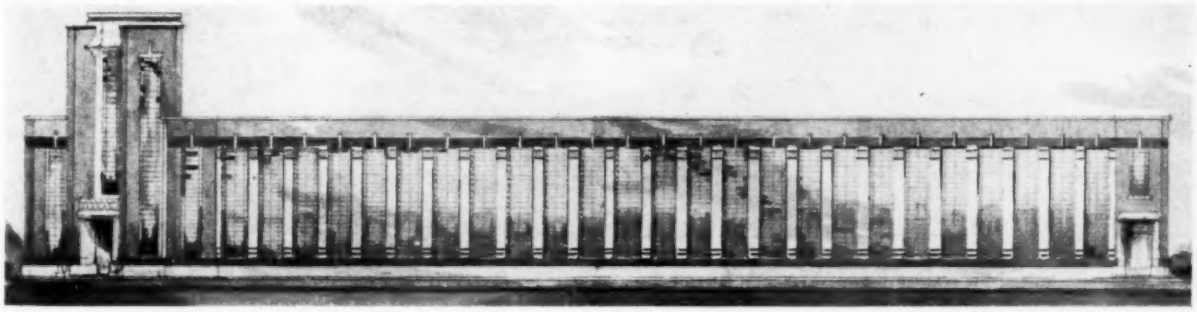
THAT the methods and processes of yesterday will not suffice for to-day or to-morrow is admirably emphasised by the remarkable progress achieved by High Duty Alloys, Ltd., in the relatively short period of twelve years since the inception of the company. At the very outset its directors recognised that one of the ways by which a firm could establish and maintain a name and reputation for quality was by active participation in research into materials and processes which would pave the way for further advances. That this policy has been successful will be appreciated when it is realised that at the outset this company commenced with five people in the laboratory and seven in the other departments; to-day it employs nearly 10,000, and, as these new laboratories indicate, the basic policy remains unchanged.

It is in the light metal field that this outstanding progress has been achieved; since the development of the now famous Hiduminium RR high-strength cast and wrought alloys. Although Hall and Héroult gave a considerable impetus to the use of aluminium by the discovery of electro-metallurgical methods of reduction which greatly cheapened the metal, the relatively low strength of aluminium retarded its application for many purposes. It was not until 1910 that Wilm developed the well-known wrought alloy, duralumin, and more important still, had discovered the age-hardening phenomenon which had far-reaching effects and gave fresh impetus to the aluminium industry and made possible a great step forward in the air-craft industry.

At that time, apart from the work of a few pioneers, Britain was lagging behind in scientific research, but the persistent work of Rosenhain and his collaborators at the National Physical Laboratory provided the next most important development; between 1914 and 1919 the well-known Y-alloy was developed for high temperature applications, and especially for aero engine pistons and cylinder heads. The tremendous outburst of energy brought forth by the world war during that period provided an impetus for research in this country, and advances in scientific achievement were accompanied by some striking engineering developments, which led to increasing demands for higher strength light alloys than were then available. It was not until 1927, however, that Hall and Bradbury developed a high strength alloy for the Rolls-Royce "R" Schneider Trophy engine that those demands could be met. This alloy became the basis of the Hiduminium RR range of high-strength cast and wrought alloys, and provided the next important development in the aluminium industry.

It quickly became apparent to High Duty Alloys, Ltd., that research was destined to play an increasing part in industrial production, and since the initial stages new alloys have been added to the Hiduminium RR range following the results of patient research to meet particular conditions of service. Parallel with the development of these alloys great strides have been made in manufacturing technique. Sand-die and ingot-casting processes have been developed, while on the wrought side pressing, extrusion, tube-drawing and rolling of sheet and strip have been added to the older forging and stamping processes of working high-strength light alloys. Methods of joining aluminium alloys have been developed, while intensive research has resulted in great progress in the development and application of methods of protection against corrosion.

The Administration Offices at the front of the Buildings, with the Main Entrance on the left.



1. The Spectrographic Laboratory. 2. Part of X-ray Crystallographic Laboratory. 3. Electro-acoustic Apparatus for Determining Damping Capacity. 4. A Section of the Metallographical Laboratory.

Progress is inseparably bound up with research, or at least in the light metal industry, and the results of laboratory research can, in almost every case, be put into practice on a production scale, provided that the operations carried on in the works are carefully and scientifically controlled by competent scientific personnel endowed with authority sufficient to ensure rigid adherence to standards laid down. In pursuance of this policy, High Duty Alloys, Ltd., have maintained adequate laboratories from their very beginning, and owing to the rapid growth of the works frequent extensions to these laboratories have been made in order to provide accommodation adequate both for research and for the scientific control of works production. In 1928, for instance, the laboratory accommodation comprised two small rooms with a total floor area of 550 sq. ft. ; to-day the new laboratories occupy a floor space of 45,000 sq. ft.—which is more than four times the total area of the entire factory in 1928.

The Laboratory Buildings

The new buildings comprise four bays, each 140 ft. long and having a span of 50 ft. Along the front of these bays is a two-storey block of administration offices, and behind them are various outbuildings housing services, cloakrooms, air-conditioning and heating plants, etc. The bays are sub-divided into various departments, including the lecture theatre, which is panelled in cork slabs, the library which is finished in cream and natural oak, the damping laboratory which is entirely enclosed in aluminium sheet, and the various X-ray rooms, which are lead lined.

Special consideration has been given, throughout the building, to secure good and healthy working conditions in every department, and to this end a highly efficient system of forced ventilation has been installed. This system supplies fresh air at constant temperature to all departments. In general, the air conditioning is at the rate of six changes of air per hour, but in certain departments where fumes are generated the rate of change is increased. In the chemical department, for instance, provision is made for twenty changes of air per hour by the air-conditioning installation, and this is still further augmented by the fume extraction plant. Particular attention has been given to the design of this fume extraction plant, which not only operates from the fume cupboards and roof, but is also carried to all analytical and filtering benches, where it extracts at bench level through controllable shutters, and at floor level. Similar exhaust systems extract fumes from the foundry via hoods over the furnaces and casting floor ; the corrosion and protection laboratory via hoods over the chromating, anodising, electro-plating baths, and from the paint spray booth ; and from the large etching sink in the metallographic laboratory.

Attached to the library is a well-equipped lecture theatre capable of seating in comfort about 100 students. Lecture courses are arranged to give the students a thorough training in theoretical and practical metallurgy proceeding concurrently with practical training.

The Spectrographic Laboratory

Quantitative spectrographic analysis seems to offer very definite advantages for accurate routine analysis of certain light alloy constituents which offer difficulties in ordinary chemical analysis. In addition, qualitative analysis for a rapid survey of general composition, in particular to the detection of impurities, is of ever-increasing importance, and the spectrographic method enables this to be done with the speed, reliability and economy necessary for large scale application in practice. This department is equipped with two medium quartz spectrographs, and, for the quantitative analysis, with four microphotometers for the measurement of spectrum line densities by means of photo-cells. For the qualitative analysis, two spectrum viewers and enlargers are provided which enable the spectrograms to be examined visually and photographed at twenty magnifications. For the development of the spectrographic plates, for which the highest accuracy in manipulation is essential, a special dark room is reserved. Furthermore,

ample accommodation and equipment for the preparation of the specimens to be used for the spectrographic analysis is provided.

The X-ray Crystallographic Laboratory

In this department X-ray methods are used for the determination of the extent and the effects of cold-work and of the crystal orientation in cast, worked, and heat-treated samples of production materials and problems referring to re-crystallisation, grain growth and grain size are under investigation. Many results of practical use have already been obtained; in particular, those concerned with the effects of working temperature and the conditions of heat-treatment, and methods have been evolved which enable a retrospective check on working conditions to be made. Systematic research work on the problems indicated is in progress. The equipment of this department includes a crystal analysis X-ray unit provided with a number of X-ray tubes with targets of various materials and a number of special cameras adapted to the various investigations undertaken by this department.

The Metallographic Laboratory

The routine work of this department is concerned with the examination of macro-structure and micro-structure of manufactured components, with a view to their suitability for service. Such work includes the metallographic examination of forging ingots to eliminate those unsuitable for forging, examination of finished components for break-down of structure, grain flow, etc., as a check on forging conditions, and the micro-examination of all types of alloy components for overheating in heat-treatment. A very important side of this work is the complete investigation of every new component manufactured. The equipment includes a Vickers' projection microscope, a Zeiss Neophot microscope, a Beck metallurgical bench microscope, three workshop-type microscopes, and a Beck binocular microscope, mounted on a special universal support for the examination of large specimens and complete components.

The Chemical Laboratory

The chemical laboratories occupy one complete bay and are equipped to carry out 500 complete analyses per day. A separate laboratory is provided for routine electrochemical analysis, in which is situated a five-bank electrolytic apparatus capable of 150 determinations per hour. This installation, which is the only one of its kind in the country, has independent totally enclosed motor control for each of its 50 units, with independent transformers and rectifiers and electrically heated controlled hot plates. There is a large chemical laboratory set aside for various research activities, such as the development of new and improved analytical methods. Attached to the chemical laboratories is a spacious balance room containing twenty-four analytical balances, of which seven are of the prismatic type.

The Instrument Workshop

This workshop attached to the laboratories is adequately equipped to construct special apparatus for any particular research in hand. Besides the construction and maintenance of laboratory equipment, this department is responsible for the maintenance of the large number of pyrometric installations in the company's works upon which depends to a great extent the accuracy of control of melting and casting conditions, working temperatures and heat-treatment. In this department also are manufactured the standard thermocouples which have been designed to meet the particular needs of this company's manufacturing processes. Adjoining the workshop is the calibration room, which is equipped to carry out rapid checks on the accuracy of the works' pyrometers and thermocouples. These thermocouples are withdrawn from service at frequent intervals for overhaul and re-calibration in this department.

Testing Laboratories

There are two testing laboratories, one devoted to experimental testing and the other confined to routine

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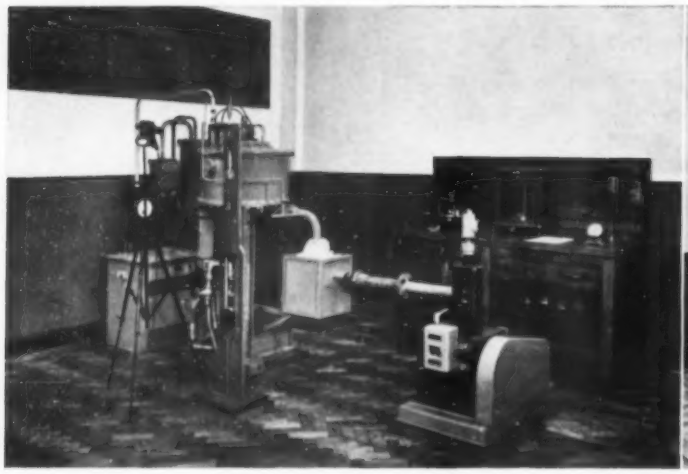
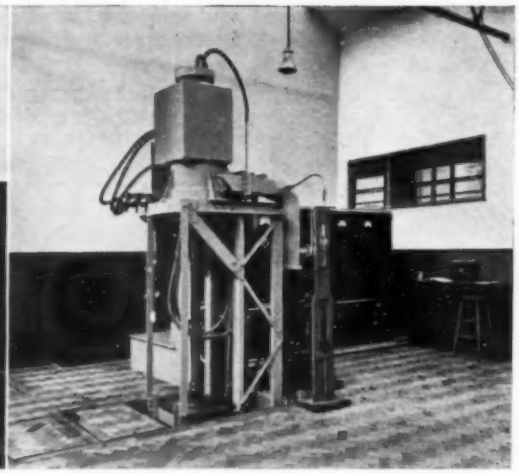
5. Part of the Chemical Laboratory. 6. The Electrolytic Laboratory. 7. Colorimetric Laboratory (Physical). 8. The Instrument Workshop.



Electric Resistance Vacuum Furnace in the Experimental Testing Laboratory.



20 kw. High-frequency Induction Furnace.

mechanical testing. The former department performs two distinct, though allied, functions. On the one hand, long-range research on a number of different lines is conducted here, and, on the other hand, the department is equipped to carry out accurate static and dynamic mechanical tests.

Obviously, the equipment of such a department will vary somewhat from time to time according to the types of research in progress. At the moment, this includes two specially designed high temperature vacuum furnaces, the one heated by electrical resistance, and the other being a 20-kilowatt high-frequency induction furnace. The mechanical testing equipment includes an Avery 15-ton beam type tensile testing machine, two Amsler Wohler fatigue testing machines, an N.P.L. rotating fatigue testing machine, a battery of creep testing machines, and an Avery Brinell hardness testing machine.

In the routine testing department a very large number of tests must be made daily as specifications for aircraft materials, or for tensile tests on each batch from the same cast from one furnace and heat-treated together. Where tests include ultimate tensile strength, 0·1% proof stress and elongation, in addition, all test-pieces must be tested for hardness for comparison with the hardness numbers of every component in the batch which it represents.

The Radiographic Laboratory

Radiological examination has already exerted a profound influence on the quality of metallurgical products. Intelligent interpretation of radiographs and collaboration with the foundrymen has produced a marked improvement in the soundness and general quality of all types of castings, and this method of non-destructive testing is now included in the routine inspection of all highly stressed cast components.

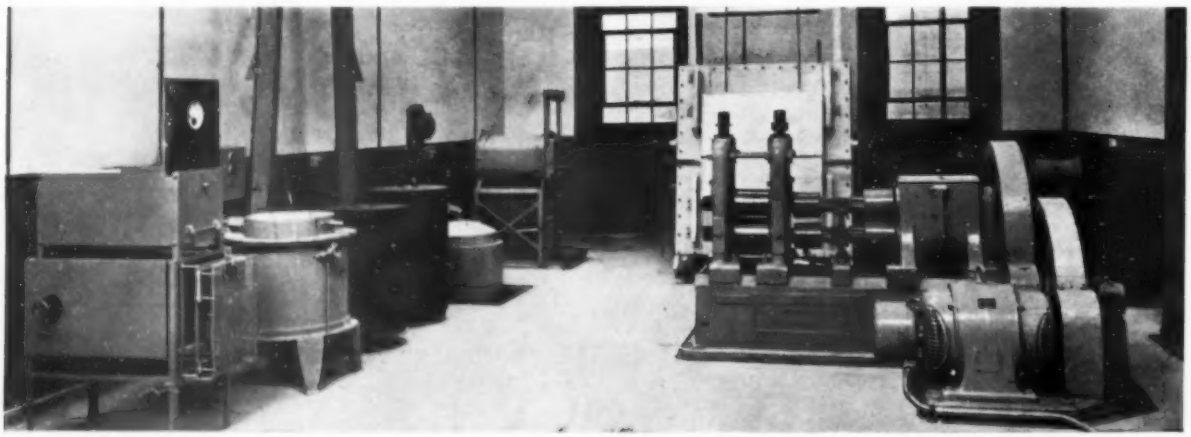
The equipment in this department includes X-ray tubes of 100 k.v., 150 k.v., and 200 k.v. capacity, each of which is housed in a separate lead-lined room with the controls situated outside in order to avoid possible ill-effects of the X-rays upon the operators.

Metallurgical Works Practice

In addition to the laboratories already noted, two departments are included which form valuable connecting links between research and works practice, these are the experimental foundry and the experimental heat-treatment department and rolling mill. The activities of the foundry include the preparation of experimental alloys, the investigation of casting properties, the development of casting methods and technique, the study, development, and control of moulding sands and the preparation of standards for the analytical departments.

It has only been possible to deal very briefly with what we regard as one of the best planned and equipped laboratories we have seen, but sufficient has been said to indicate the value that High Duty Alloys place on industrial research in order to ensure that aeronautical designers shall have the improved materials they require for the increased performance of their designs and to maintain the high standard of reliability. The company is to be congratulated on its enterprise.

Experimental Heat-treatment Department and Rolling Mill.



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The War Goes On and On

TO debate outspokenly the conduct of a campaign while the enemy threatens to renew the attack at any moment is typically British. It is an expression of the democratic right to criticise the Government of the day for any shortcomings in performing its functions. But this does not indicate a lack of appreciation of what Mr. Chamberlain has done; he has faithfully carried out the wishes of the great majority of the people of this country. He is a man of peace, and the fact that he has been no match for the enemy in ruthlessness is not surprising, but when it is realised how much has depended upon his leadership, the manner in which he has stood out in this critical phase of British history will long be a source of wonder, and the speech he made in which he offered his services to his successor further increased his political stature.

It should be remembered that the severest critics of the recent Government in the House of Commons debate were concerned about the means employed in organising the full resources of the country against the common enemy. All have the same end in view, but the critics feared complacency and lack of driving force, which brings about muddle and waste. It is, of course, true that in time of war the general public must allow the Government to assume powers which it would not think of allowing in time of peace. In general, the inhabitants of this country are fully prepared to bear with these incursions on their liberties, which are ordinarily regarded as their rights, on conditions. Of these, it is an indispensable condition of their willingness to submit that the wide powers possessed by the Government carry the assurance that they will not be exercised arbitrarily or without the opportunity of popular and public criticism and control.

Those who advocated in the early days of the war that during the period of hostilities Parliament should not often assemble, and then only to ratify the acts of the inner Cabinet or Executive, and to confer upon it such additional powers as it demanded, have been proved wrong, and after the recent storm in the House it is doubtful whether any advocates of this policy remain. But the frequent meetings of the House of Commons since the outbreak of the war have demonstrated their value in affording opportunity for the exposure of scandals and inefficiencies, and the ventilation of public grievances and complaints. This does not mean that deficiencies of the Government, or public grievances and complaints, are immediately removed by such criticism, but it does bring the pressure of public opinion to bear upon the holders of office, high and low, and tends to promote efficiency.

This characteristic safeguard has already proved of value in many directions during this war, and it is likely that it will be needed more and more as the increasing stringency of war conditions makes further demands on freedom, as the range and severity of control extend. It is very unlikely that any possible executive would be gifted with a hundred per cent. efficiency in its direction of operations against the enemy, and the pressure of public opinion is necessary in obtaining as high an efficiency as possible.

Actually, exaggerated optimism and complacent satisfaction had had a severe jolt over the Norwegian affair, and it was due to what was regarded as a flagrant lack of direction and driving force in anticipating and opposing the Germans in Norway that the storm arose in the House of Commons. It is known that the late Prime Minister was favourable to long-term strategy, and by simply expressing assurance that we would win in the end, gave the impression of being too complacent. It is this fear that complacency exists in high quarters—that the long-term strategy idea was being carried to lengths which did not satisfy the public. The opposition to the recent Government in the House, as indicated by the debate, was really a reflection of public opinion in its growing demand for a more active war policy.

Although the cause of the recent criticism in the House of Commons was primarily due to the withdrawal of troops from various Norwegian areas that had been occupied, many other aspects seemed to indicate a lack of driving force. There was need for more authoritative co-ordination of all Government departments to ensure the efficient prosecution of the war and to secure swift and complete action in all fields, on land, sea and in the air. Apparently we are still far behind Germany in air power, and yet up to the present have not taken advantage of our labour reserves to bring about parity at a quicker rate.

The opinion may be expressed that the large number of unemployed available are unsuitable for the construction of aeroplanes because of the high degree of skill necessary. This view is certainly true as regards the building of aero engines, but does not apply to the construction of the aeroplane to anything like the same degree. It must be remembered that the aeroplanes recently built, and which are giving such a remarkably good account of themselves, were constructed mainly by men who, only a relatively short time ago, were also unemployed, and who had no previous experience of aeroplane construction. We believe we shall now see the Government Department concerned initiate such a drive for increased production that much additional labour will have to be absorbed to increase the delivery of finished planes. But this applies also to all other sections of activity which are concerned with the waging of war, whether they are directly engaged in producing for the Forces or concerned with economic warfare.

In this war against a highly organised but ruthless enemy the full resources of this country should be organised and directed in the most forceful manner consistent with efficiency. Direction in the waging of this war is too complex for it to be of an instinctive character; it must be scientifically directed in an effort to balance the economic, technical and psychological factors which will contribute to success, and the men chosen to direct the nation's destiny at this critical time must have the confidence of the nation, and be capable of uniting all forces in the more efficient and more energetic carrying out of the nation's demands.

The House of Commons has again demonstrated the solid unity of the British people in face of the gravest threat this country has ever been called upon to meet. Unity is a mighty factor in a war of nations, and with more efficient administration and a more effective drive, we are confident that victory will be achieved.

In view of the control of paper, to ensure a regular supply of copies of each issue of METALLURGIA, readers are asked to order in advance, either through their newsagents or direct from the publishers, Kennedy Press, Ltd., 21, Albion Street, Gaythorn, Manchester.

Voluntary Savings

TWO of the most striking features of the Budget were the tribute paid by Sir John Simon to the voluntary savers of the country, and his action in removing from the operation of the Means Test the first £375 of war-time savings. Although Sir John Simon had no option but to increase heavily the burdens on industry, he has made it easier for those portions of the community whose incomes have been increased by war demand to lend their new surplus—however small—to the nation.

The duty of every one of us to spend wisely, and save sagely, has a double effect. It not only provides the Exchequer with the money for war purposes, but it also helps to prevent rising prices, inflation, and the over-burdening of valuable ship cargo-space.

In the first 21 weeks of the War Savings Campaign more than £130,000,000 has been subscribed in Defence Bonds and National Savings Certificates in the first five months of the campaign. There are now between 70,000 and 80,000 Savings Groups through which a steady stream of money is passing from the private to the national purse. More than 30,000 of these, or nearly half, have been formed in these five months. About two-thirds of these have been formed in factories, workshops and places of business. There are still an estimated 200,000 factories and workshops in which Savings Groups can be usefully formed.

The many millions of lower-paid workers who have escaped much of the demands of direct taxation imposed by the Budget are ready to do more than give their labour, their sons and their husbands for the war effort, and it is the duty of every employer of labour to see to it that the proper machinery is set up by which they can do their bit by lending to the State what they do not actually need for themselves.

The purchase of Savings Certificates is not solely a patriotic duty. It is a sound business investment. It is a check on the inevitable war-time tendency of inflation; it gives everyone a stake in the nation's wealth, and it is storing up a vast volume of purchasing power to help trade during the difficult period of transition to a peace-time basis after the war.

Experience is showing nearly every day that workpeople are anxious to save if given a chance to do so by employers. Any employer who ventures the opinion that his people will not save, if given the opportunity, will find he is mistaken. There have been numerous examples recently of 50% and even 90% of employees volunteering to join savings groups in factories where the employers have hesitated to start a scheme for fear of a poor response.

It is not desirable for employers to badger unwilling contributors. All that is asked of employers is to set up the machinery for organised saving. If the response is poor, it will be well for the employer to find the cause. Sometimes the scheme has not been properly explained to the worker. If so, a speaker can be sent from the National Savings Committee.

There need be no delay in setting up a group because the labour in running the group is small, and generally one member can be found in a firm to push the scheme with energy and enthusiasm. The Savings Committee supply all necessary printed forms, and any system is simple and easy to work. For factory, shop or warehouse the best method is that of Scheme 6, by which a regular weekly deduction is made from wages. This is popular with workpeople on the principle that what they do not receive they do not miss.

There are many ways in which the employer can encourage the scheme. The first of these is for him to buy Certificates in blank with the advantage to the employee that interest accrues from the date of his first payment. The only cost to the employer is the 15 or 30 weeks' interest on the purchase price of the Certificates, according to whether 1s. or 6d. a week is paid in.

Many employers, as a further encouragement, buy the Certificates at 15s., and sell them to their employees at 14s. 6d. or 14s. A few firms sell them at 13s. 6d. Other employers present a number of Certificates to be balloted for in a series of prizes, the ballot being open to all who have joined a Group. Such ballots have proved an incentive to saving. Experience shows that many small prizes are preferable to a few large ones. Some employers are paying a weekly or monthly bonus in the form of Certificates.

When a scheme shows signs of lack of life a ballot scheme for a few Certificates is often a wonderful incentive to wake things up. It should always be remembered that no Group can be too small or too large, and that it should be looked upon as a national duty by an employer to interest himself in setting up a Savings Group for his employees.

Institute of British Foundrymen

THE thirty-seventh annual conference of the above Institute will be held at Cheltenham on June 7 and 8, at which the following papers will be presented for discussion:—"Chromium Alloy Heat-resisting Cast Iron," by R. C. Tucker, M.A.; "The Production of Pressure-resisting and High Duty Iron Castings," by J. L. Francis; "On Developments in Gating and Risering for High Shrinkage Alloys in High Test Cast Iron," by A. E. Cartwright and C. C. Brisbois; "The Extended Use of Cast Iron with Special Reference to War Conditions," by J. G. Pearce, M.Sc., M.I.E.E., M.I.Mech.E., F.Inst.P.; "The Design of Test Pieces for Carbon Steel Castings," by C. H. Kain and E. W. Dowson; "Gas in Liquid Cast Iron," by W. Y. Buchanan; and "Observations on Contraction in Cast Iron," by E. Longden.

The programme arrangements include a dinner at the Plough Hotel on June 8, to be followed by a dance to be held in the Town Hall.

Catalagzi Power Scheme, Turkey

IT is now possible to give details of the important contract which has been signed between the Turkish Government and a British engineering firm. The contract is between the Turkish Government institution known as the Eti Bank and the Metropolitan-Vickers Electrical Co., Ltd., and it covers an electrification scheme including the construction of a power station at Catalagzi, on the Anatolian coast of the Black Sea. The order, which has been obtained in the face of international competition, has a value of approximately £1,500,000.

The scheme has as one of its main objects the provision of electric power for the modernisation and expansion of the Turkish coal industry, and the site of the station has been chosen for its proximity to the Zonguldak coal basin, from which the station fuel will be derived. The present contract includes the building and equipment of a 60,000 kw. power station, and the provision of switchgear, overhead line, and three sub-stations for a transmission system about 16 kilos. in length. Provision is to be made for extension of the scheme at some future date.

The initial generating plant will consist of three 20,000 kw. turbo-alternator sets to operate at 3,000 r.p.m. with Metrovick central-flow condensers and four-stage feed-heating incorporating low-pressure evaporators for make-up supply. Sea water will be used for cooling, and will be supplied from a separate pump-house to be constructed on the shore. The main alternators will generate at 11,000 volts, and each set will include a 1,500 kw. house-service alternator. A 375-kw. Diesel engine set will also be provided for stand-by service to the station auxiliaries.

Transmission to the sub-station will be at 66,000 volts, the station output being stepped up to this voltage by an outdoor transformer and switching station adjoining the power station and controlled from an indoor control board. The main transformers will be 25,000 kva., 11/66 kv., three-phase units. The equipments of the sub-stations will include nine 6,400 kva., 66/15 kv. outdoor transformers, and 15 kv. indoor switchgear.

The Estimation of Hydrogen in Steel and other Metals

By W. C. Newell, Ph.D., D.I.C., A.R.C.S., B.Sc., A.I.C.

(The Brown-Firth Research Laboratories, Sheffield).

The development of the vacuum-heating method of estimating hydrogen in metals is described, with special reference to steel. The theoretical basis of the method is discussed, and a description of an apparatus is given, together with results of tests upon the method itself and upon metal samples. It is abstracted from Paper No. 1/1940 of the Oxygen Sub-Committee of the Heterogeneity of Steel Ingots Committee, presented at the May meeting of the Iron and Steel Institute.

THE ever-growing and more exacting requirements of the engineer, since the beginning of the present century, have caused the metallurgist to devote more and more of his energy to improving the quality of his product. An enormous amount of fundamental research has been conducted into the correlation of the physical properties of metals (especially steel) with their precise mode of production, their chemical composition and their constitution. The discovery that very small additions of other elements can radically affect the properties of metals has added impetus to the development of micro-chemistry, but there are certain non-metallic elements which, whilst influencing the properties of metals, even when present in minute amounts, call for a specialised technique, more physical than chemical, since they enter or leave the metal in the form of gas.

Foremost among the gases which influence the properties of metals is hydrogen, and the object of this paper is to describe an apparatus which has been developed at the Brown-Firth Research Laboratories, Sheffield, for the accurate estimation of hydrogen in metals, in an effort to assist others seeking to apply the fruits of science to constructive purposes.

In 1918 the Faraday Society held a general discussion upon the "Occlusion of Gases by Metals," which has since been published,[1] and to which reference should be made for a summary of the various views held at that time. The more recent work which has been done upon the hydrogen content of metals has, for the most part, utilised modern high-vacuum technique in the light of the theoretical advances which have been made. The consequence is that, as usual, our knowledge is both more complete and more complex. The mechanism whereby hydrogen is taken up by, or liberated from, a metal involves the processes of adsorption, solution and diffusion. It is to Langmuir[2] that we owe the concept of a mono-molecular layer of physically adsorbed gas. More recently the work of Roberts[3] on the hydrogen-tungsten system and the work of Mann and the present author[4] on the hydrogen-platinum and deuterium-platinum systems indicate that where some chemical affinity exists between the gas and the metal, then at normal temperatures a layer of gas is chemisorbed even at very low gas pressures. The method of examining the metal surface in these experiments consisted of a measurement of the accommodation co-efficient of neon or helium upon the surface. The importance of this to our considerations here is that since adsorption is a necessary preliminary to the diffusion and solution of the gas in the metal, the rate of removal of the gas from the metal will be influenced by (if not primarily dependent upon) the rate of the desorption processes. Since an adsorbed layer of gas can be quite stable upon a metal surface even in quite low gas pressures, it seems likely that in much of the work which has been done upon the removal of gas from metal, the long period of time found necessary for complete removal is due to the fact that the extraction pressure has not been low enough, so that the diffusion process has been hindered by the adsorbed layer. In the apparatus to be described a high vacuum is maintained by a mercury-vapour pump in continuous operation, and it is suggested that this may account for the relatively short period of time found necessary for complete extraction of the hydrogen.

At temperatures at which the diffusion of hydrogen through metals can be measured, adsorption is of the activated type, and since thermo-chemical data for activated adsorption indicate dissociation of the diatomic hydrogen molecules, it is not surprising that the rate of diffusion is proportional to the square root of the gas pressure. However, at low gas pressures the rate of diffusion of hydrogen deviates from the square-root relationship and approximates more to a proportionality to the pressure.[5] Since these measurements of diffusion involve the gas pressure external to the metal surface, the process of adsorption may influence them, so that it is quite possible that at low gas pressures the condition of the adsorbed gas may control the passage of gas through the metal.

As regards the effect of temperature upon the rate of diffusion of hydrogen through metals, both experiment and theory give an exponential relationship, so that for the elimination of the gas from the metal it should only be necessary to exceed a certain temperature, and then the rate of elimination should increase rapidly with rise in temperature. This was found to be so for steel, as will be seen from the family of graphs shown in Fig. 2.

Results and Applications

Since vacuum-fusion is the method generally accepted as reliable, and has for a long while been employed in these laboratories with great confidence, a careful comparison with results obtained by this method has been kept throughout the investigation; the same sized samples were used throughout ($\frac{1}{2}$-in. cylinders, $\frac{1}{2}$ in. long). The possible error due to the "blank" in the vacuum-fusion apparatus was higher than was desired (sometimes amounting to 0·00005% of hydrogen on the metal sample). However, differences between the results by the two methods were for a while greater than this, even when the vacuum-heating method was operating under what were found to be the optimum conditions. The reason for this, we are sure, was not due to error in either method, but rather to segregation of the hydrogen in different parts of the metal, or else to the loss of hydrogen resulting from the sample getting too hot during machining. Samples which had a normal hydrogen content were found to give a somewhat lower value if during machining the piece became too hot to handle, or still more so if there was any temper-colouring produced upon the surface. Small steel castings were found to vary considerably in their hydrogen content at different parts, and much of our earlier perplexities were connected with this fact.

Table I shows a comparison of the results by the two methods for a number of metal samples. There appears to be a tendency for the vacuum-fusion method to give slightly higher results than the vacuum-heating method. The

1 *Transactions of the Faraday Society.* 1919. Vol. 14, pp. 173–277.
2 Langmuir: *Journal of the American Chemical Society.* 1915. Vol. 37, p. 1139.
3 Roberts: *Proceedings of the Royal Society.* 1935. Vol. 152, p. 445.
4 Mann and Newell: *Proceedings of the Royal Society.* 1937. Vol. 158, p. 397.
5 Borelius and Lindblom: *Annalen der Physik.* 1927. Vol. 82, p. 201.

reason for this appeared to be that the heating treatment had not extracted all the hydrogen, but the fact that several samples on vacuum-fusion subsequent to vacuum heating gave no further evolution of hydrogen discredits this view. The number of significant figures given has been reduced so as to make full allowance for the experimental error of each method, and it will be seen that the accuracy of the heating method is ten times that of the fusion method. The temperature of operation for the heating method was 600° C., excepting for the aluminium alloy samples, which were found not to give off their hydrogen until they were actually molten. These aluminium alloy samples were therefore inserted in small slip-cast alundum thimbles, in which they were melted in the furnace at about 700° C., cooled out of the furnace and when solid again manipulated in their thimbles as solid metal samples. The results for these aluminium alloys have not been stated as accurately as for the iron and steel samples, since there have not been any independent checks and the conditions under which the gas is evolved have not been so closely studied.

TABLE I.

COMPARISON OF THE RESULTS OBTAINED BY THE VACUUM-FUSION AND BY THE VACUUM-HEATING METHODS.

Sample.	Hydrogen, %, by— Vacuum-Fusion Method.	Vacuum-Heating Method.
0.08% carbon steel (cast 52703)—		
Ingot	0.00035	0.000340
2 in. rolled slab	0.00015	0.000130
¾ in. rolled bar	0.00015	0.000110
Box test	0.00015	0.000125
0.20% carbon steel, forged bar	0.00010	0.000100
3% nickel steel—		
Ingot top	0.00065	0.000620
Ingot bottom	0.00095	0.000920
4.5% nickel steel—		
Forged	<0.00005	0.000015
Box test, unkilled	0.00005	0.000067
Same cast, box test, aluminium-killed	0.00020	0.000175
4.5% nickel steel—		
Ingot bottom	0.00005	0.000040
Bath sample	0.00010	0.000060
Another bath sample	0.00025	0.000230
5% nickel steel, ingot bottom, outside	0.00020	0.000170
18% chromium, 8% nickel steel—		
Bath sample	0.00060	0.000675
Another bath sample	0.00090	0.000870
Ingot top	0.00095	0.00109
Same cast, ingot bottom	0.00100	0.000995
Box test, unkilled	0.00085	0.000840
Swedish iron, 0.04% carbon	0.00020	0.000200
Aluminium alloy, 4% copper	Operating	0.00021
" " "	temperature	0.00017
" " 12% silicon	too high	0.00015
" " "		0.00018

The role of hydrogen as a possibly deleterious constituent of metals is well recognised, and this apparatus not only has its applications in this direction, but also for the fundamental study of gas-metal equilibria, and the solution and diffusion of hydrogen in alloys.

The Apparatus

A diagrammatic sketch showing the working principles of the apparatus is shown in Fig. 1. The heating furnace is a fused-silica tube round the upper end of which a well-lagged nickel-chromium resistance coil is wound. This silica tube has a ground joint at its lower end, which fits a corresponding pyrex-glass tube leading to a glass mercury-vapour pump. For convenience this mercury-vapour pump is also in pyrex glass, so that from the silica-joint onwards the apparatus through which the gas has to pass is in one piece, the mercury-vapour and the Töpler pumps having been sealed-on in position. The mercury-vapour pump is connected, via quill glass tubing, to a combined Töpler pump and McLeod gauge, the function of which is both to collect the gas and measure its quantity. The upper portion of this pump (which is called a Töpler pump for convenience)

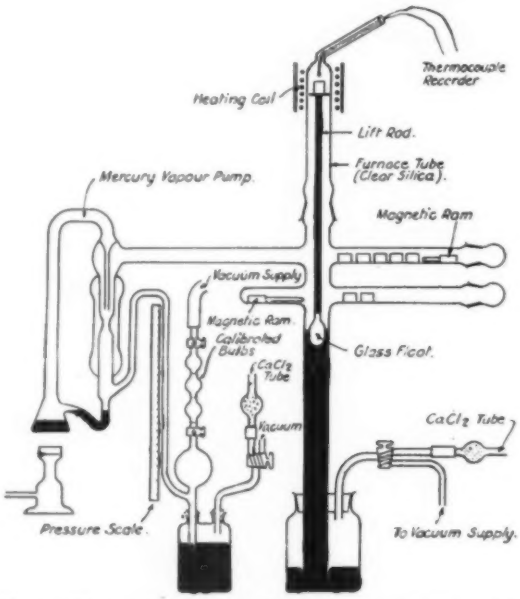

Fig. 1.—Diagrammatic sketch of the apparatus used for the vacuum heating method of estimating hydrogen.

is joined to three small calibrated bulbs, isolated by taps, into which the gas collected can be compressed and its volume and pressure recorded, by taking the height of the mercury in the adjacent vertical tubing. These bulbs are graduated, the upper one being smaller than the middle one, which is itself smaller than the lower one, so that considerable variations in volume of gas can be dealt with. About seven-eighths of the gas collected is swept up and compressed by one operation of the Töpler pump, so that in order to save time in taking readings of gas quantity, only one sweep of the pump was normally taken, and the precise factor, to convert this quantity measured to the total quantity of gas given off from the specimen, was experimentally determined.

A striking feature of the apparatus is the mercury lift used to move the samples vertically in and out of the furnace. A sealed glass bulb floats upon the mercury surface in the central glass tube, and supports a long steel rod on the top of which a steel platform is attached to support the metal samples. The position of this platform, together with its sample, is determined by the pressure in the bottle on the right-hand side of the sketch, and out of view in the photograph, since it is below the bench level. Thus, by a turn of the three-way tap either to the atmosphere or else to the vacuum supply, the platform can be brought to :—

(1) The level of the upper horizontal tube containing unexamined metal samples, for the purpose of a sample being magnetically pushed on the platform.
(2) The level of the centre of the furnace, near which is a thermocouple for the purpose of recording the temperature.
(3) The level of the lower horizontal tube, into which the metal sample is magnetically pushed after its heat-treatment.

This mode of performing mechanical operations *in vacuo* with the aid of mercury surfaces, controlled externally, has proved itself very valuable, and superior for the present purpose to the purely magnetic control at first employed.

Preliminary Experimental Work

The Composition of the Gas Evolved.—The experiments of other investigators indicated that under certain conditions gas other than hydrogen could be given off from metals on heating, so that in the original form of this apparatus an activated-charcoal pocket was sealed in between the furnace and the mercury-vapour pump. This was employed as a quick means of determining the actual amount of hydrogen as well as the amount of other gas, since in a high vacuum

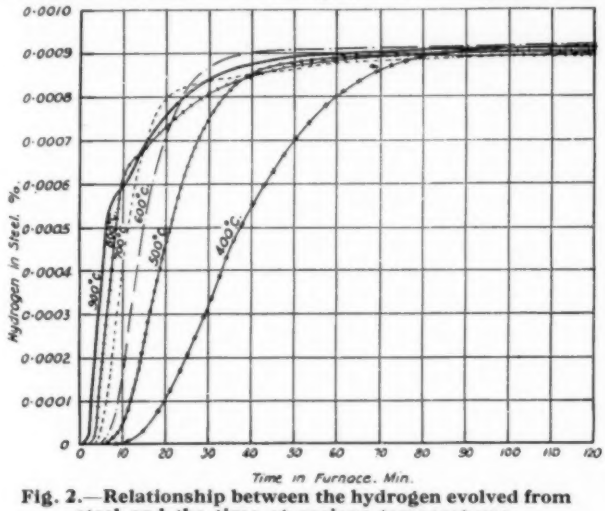

Fig. 2.—Relationship between the hydrogen evolved from steel and the time at various temperatures.

charcoal does not absorb any permanent gas unless the temperature is artificially lowered, when, at the temperature of liquid air, all gases except hydrogen are absorbed. The method of examining the gas was, therefore, to measure the quantity which passed through the charcoal pocket when surrounded by liquid air; this gave the hydrogen value. Then by removing the liquid air and allowing the charcoal to warm up to room temperature, any increase in the reading corresponded to gas other than hydrogen. Water vapour was invariably a constituent of the gas collected, unless the metal samples used were very bright and clean—and even then they came out of the apparatus brighter than when they went in. Where the quantity of water vapour was considerable, small droplets of water were visible in the Töpler pump during the compression of the gas. The simplest method used for detecting water vapour, when the quantity of it present was small, was to observe the pressure of the gas when it was compressed to different stages. Any departure of the product of the pressure and the volume from being a constant indicated water vapour. Since the presence of water vapour was invariably associated with a brightening-up of the surface of the metal, it is reasonable to assume that the water vapour was produced by a reduction of an oxide film by the hydrogen being evolved from the surface. However, in such a reaction:

$$FeO + H_2 \longrightarrow Fe + H_2O,$$

the volume of the water vapour formed is equal to the volume of hydrogen oxidised, so, provided that no water is actually condensed out in the form of liquid, the volume of the system remains unaltered by the reaction. Hence all the metal samples were very carefully cleaned before examination, and the gas evolved was not unduly compressed.

Under all the conditions of study the gas given off from steel was substantially hydrogen, but at temperatures above 700° C. small amounts of carbon monoxide and nitrogen made their appearance, particularly the latter. As the temperature was raised the quantities of these gases evolved increased, and at a temperature of 1,000° C. nearly 10% of the total gas was accounted for in this way. It will be noted that the apparatus was designed so as to avoid contact between the metal samples and the heated silica furnace tube, since it has been suggested that oxidation of carbon from steel can take place in this way. Certainly the quantity of carbon monoxide found was small, and the most which was collected at a temperature of 1,000° C. only corresponded to 0·0008% of oxygen in the steel so treated. Nitrogen was given off in somewhat larger quantities at these higher temperatures, and for the sample just referred to the nitrogen corresponded to 0·003% of nitrogen in the steel. The total nitrogen content of this steel, as shown by vacuum-fusion, was only 0·008%, so that a substantial proportion had been driven off from the solid.

The Blank.—In an apparatus of this kind, constructed in glass and silica and having no graphite parts, the question of the "blank" really does not arise. The normal high-vacuum technique is applied in its construction, and the whole is thoroughly out-gassed before use. The furnace itself never caused any permanent evolution of gas, and that which was given off during the out-gassing period was mainly water vapour. For the sake of interest the "blank" was determined over a period of a month when the apparatus was not being otherwise used. The figure obtained came out at 0·00001 ml. per hour, and this is probably due to incomplete out-gassing rather than a leak. Hence no regard has to be taken at all for any "blank" correction.

The Effect of Temperature.—Temperature readings were obtained by a thermocouple and recorder, the thermocouple being inserted in a narrow tube at the top of the furnace and projecting down towards the centre of the furnace. The metal sample and platform were brought up close to the thermocouple, and the uniformity of the temperature was checked by bringing the metal sample into contact with the thermocouple, when no change in the reading was observed. At the higher end of the temperature range the temperature of the thermocouple and the sampe were found to be closely the same when using a disappearing-filament pyrometer.

The effect of temperature upon the rate of evolution of hydrogen was studied, using a steel sample somewhat high in the gas, since it was thought that if the gas was present in the steel in different forms, then such a study ought to give evidence of the fact. Actually, no such evidence was obtained. A number of samples were cut from closely adjacent positions in an ingot, and were raised into the furnace at different temperatures, the hydrogen given off being measured at frequent intervals of time. It was found that gas was rapidly given off at temperatures above 500° C., the initial lag being reasonably accounted for as the time required for the sample to be heated. Above 900° C. the rate of evolution of hydrogen was so rapid that accurate readings could not be obtained quickly enough, whilst below 400° C. the rate became distinctly slow.

The conclusion of importance which was reached was that the total amount of hydrogen given off from the steel was independent of the temperature to which the steel was heated—this will be seen from the graphs reproduced in Fig. 2,—and that this amount was equal to the amount given off by vacuum-fusion. It will be observed from these graphs that at temperatures above 700° C. the curves show an irregularity which causes them to cross. The most likely explanation of this phenomenon is that on passing through the Ac_1 point the liberation of the hydrogen is in some way hindered.

After it had been shown that no further evolution of hydrogen occurred when steel samples, which had already been vacuum-heated, were melted *in vacuo*, the conditions of extraction were standardised at 600° C. for 1 hour. These conditions have been proved satisfactory for many different types of steel, but occasionally it is found that hydrogen is still being very slowly evolved after the period of 1 hour. If this occurs, then the period of heating is extended, maybe to 2 hours or more until a constant value is obtained. No explanation of this effect can as yet be given, though it is thought to be possibly related to the influence of the structure of the steel upon the diffusion of hydrogen.

Correspondence

The British Machine Tool Industry

The Editor, METALLURGIA.

Dear Sir,

I have read with great interest your article on the British machine-tool industry in your March issue, but I am surprised that this article does not mention the subject of the penal taxation now in operation, which bears most heavily upon a trade so liable to serious fluctuations as ours.

It is an astonishing thing to me that the iniquitous and inequitable principle of over-taxing profits beyond an arbitrary standard should be revived. I had thought it was widely known that the depression which persisted nearly throughout the last decade, especially in the engineering trades, was largely caused and most certainly aggravated by the incidence of E.P.D. It was not possible to build up adequate reserves during the good years, with the result that many firms were driven into liquidation, and nearly all were gravely crippled.

The record of that appalling period constitutes a monument to the folly and incompetence of the so-called statesmen of 20 years ago. Alas, the present Government includes several of them, and, perhaps naturally, their new colleagues have embraced all their heresies. In dealing with the problems of the industry, therefore, arising from the present war, I would say that, if it depends on any Government, we may look forward to general commercial ruin.

Happily, I am not without confidence in the resiliency of "business" once the bureaucratic thumb is lifted. It is too much to hope for a commercial revolution which would thrust that thumb aside.—Yours faithfully,

John Stirk & Sons Ltd., J. G. STIRK.
Halifax.
April 11, 1940.

[The inequitable principle of over-taxing profits beyond an arbitrary standard, to which Mr. Stirk refers, was dropped in 1937, and a flat rate N.D.C. imposed of 5%—subject to certain minor reasonable adjustments. It was, however, revived in 1939.—EDITOR.]

The Editor, METALLURGIA.

Dear Sir,

I have read, in your April issue, the several interesting letters and your further editorial comment on the British machine-tool industry discussed in your leading article of the previous issue. I have previously congratulated you on that leading article and agree with practically all the views expressed therein.

Whilst I am vitally interested in the machine-tool trade, and agree that difficulties peculiar to that trade should be dealt with by people connected with it, I want now to present the view that other industries, besides the machine-tool industry, were faced with similar difficulties at the end of the last war, and we want a solution which will apply equally to industry as a whole.

It will be generally agreed that the major trouble in the past has been that industry has failed to realise the importance of keeping our plant and equipment up-to-date in order to keep in the forefront of the struggle for the world's trade. I am firmly convinced that if every manufacturing business in the country replaced a reasonable proportion of its obsolete plant each year, all our troubles would be half solved.

On this subject a letter appeared in the *Manchester Guardian*, on the 20th inst. over my name. I think the proposal it contains is practical, and, if adopted, would have tremendous effect on all classes of manufacturing industry. The following extract from that letter explains the proposal:

"I want to prevent British industry from handicapping itself in future by using obsolete plant, and this object would be achieved by changing the system under which all manufacturers receive the benefit of an allowance each year for wear and tear (depreciation) on their machinery and plant, thereby reducing the amount of income-tax payable. When the Exchequer introduced the system of making allowance for wear and tear, it was on the understanding that the industry receiving the benefit would spend on new machinery each year an amount at least equivalent to the allowance. Experience shows that industry generally has never regarded it in this way. Certainly it was not so regarded in the years 1920 to 1933. The benefits for allowances are considered as rebate in the amount of income-tax to be paid on profits."

My plan would be that income-tax payments should be collected in full and each manufacturer credited with the right and proper allowance for wear and tear in accordance with the existing standards and the amount of this credit held in a suspense account until the manufacturer required the money for the provision of new plant and equipment to replace obsolete machinery which should be scrapped. It is the custom in many countries to use in their accounts a figure for depreciation which closely approximates the allowance which the income-tax authorities admit to cover wear and tear, but it does not follow automatically that a company spends this allowance in replacing obsolescence.

Wear-and-tear allowances on machinery and plant vary, but here can be argued that at present it is approximately 10% per annum. The adoption of my plan would mean that something like 10% of the manufacturing equipment of the country would be replaced each year, which would have the effect of providing a very substantial amount of business in our country, and it would guarantee a large measure of employment in all industry, and employment means prosperity. I cannot think anyone will argue that it is bad economy to spend money in replacing obsolete machinery by the best that can be obtained, especially in a country which must keep efficient to compete successfully for business all over the world.

To indicate the effect of this proposal I would point out that the report of the Commissioners of Inland Revenue for the year March 31, 1938, shows that the total allowance for wear and tear amounted to £122,303,429 for all industries in Great Britain and Northern Ireland. At the present rate of income-tax this represents an allowance to industry of over £45,000,000 sterling per annum. To obtain the benefit of this sum industry would have to spend at the rate of £122,000,000 per annum in keeping its machinery, plant, and equipment up to date. With this volume of business at home the tempo of development would be accelerated and the reduction in our costs of manufacture would astonish the world, so much so that I am sure we should obtain a much bigger proportion of export business than ever before.—Yours, etc.,

Vauxhall Works, J. R. GREENWOOD, Chairman,
Reddish, Messrs. Craven Bros. (Manchester), Ltd.
Stockport.
April 22, 1940.

Laboratories for Radiographic Testing

As an indication of the importance attached to the X-ray testing of materials in the non-ferrous industry and also in the welding industry, it is interesting to note that one of the pioneering concerns in this country—Commercial X-rays, Ltd.—have found it necessary to establish a branch complete with laboratories and offices in Birmingham.

In the early stages of this most modern of metallurgical developments it was possible to meet all demands from the headquarters in West London, but the industrial applications of X-rays have advanced so rapidly in recent times that it has been found necessary to establish branch works in the principal centres of industry, and the Midlands—the home of the non-ferrous industry—has naturally received first consideration. To facilitate and speed up the service therefore Commercial X-rays, Ltd., have established radiographic testing laboratories and offices at 53, Wentworth Road, Harborne, Birmingham, 17, where a complete service is available.

Researches into the Structure of Alloys

A number of related researches carried out in the last few years are described in this paper by Dr. A. J. Bradley, Professor W. L. Bragg, and Dr. C. Sykes. It was presented in two parts at the May meeting of the Iron and Steel Institute. Part I deals with the investigation of equilibrium diagrams by means of X-ray analysis, in particular the analysis of binary and ternary diagrams with the component metals chromium, iron, cobalt, nickel, copper, and aluminium. Structures of sub-microscopic order of magnitude and the theory of the order-disorder transformation are also reviewed. Part II deals with the experimental investigation of the order-disorder transformation, using the alloys of β-brass, Cu_3Au, Cu_3Pd, and Ni_3Fe. The values found for the energy of the transformation are in satisfactory agreement with those predicted by the theoretical treatments given by Bragg and Williams, Bethe and Peierls. The thermal methods specially developed for the above investigation have also been employed to determine the specific-heat/temperature curves of iron, nickel and a number of age-hardening alloys. The results obtained from consideration of these curves are recorded. The work covered is reviewed in an introduction by Professor Bragg, from which this extract is prepared.

FOR some years the British Iron and Steel Federation has supported certain researches into the structures of metals and alloys by the methods of X-ray analysis. A special panel, the "Structure of Alloys Research Panel," was formed, consisting of Dr. W. H. Hatfield, Dr. A. McCance, Dr. T. Swinden, with Mr. E. C. Evans in a secretarial capacity, to receive reports of the work which has been carried out under the general supervision of Professor W. L. Bragg, and generally to discuss the implications and assist in achieving co-ordination with practical metallurgy. Dr. Bradley, Dr. H. Lipson and their collaborators have been especially concerned with the investigations of atomic arrangement in alloys. Dr. Sykes, of Metropolitan-Vickers, has dealt with physical properties of structures the atomic arrangements of which had been established, such as specific heat, electrical resistance, and rate of attaining equilibrium. It is the purpose of the present report to summarise the results, and to indicate the relation of the work which has been done, and that which it is proposed to do, to some of the outstanding problems concerning the properties and behaviour of materials used in industry.

At the risk of repeating a story which has often been told, it is perhaps justifiable to indicate the nature of the new line of attack on problems of metal structure, which has been made possible by X-ray analysis. Certain scientific methods of studying metals have long held the field, and their value has been so well established that no one would now challenge their usefulness in practical everyday problems. Chemical analysis is essential because the mechanical properties of metals are influenced in a fundamental and complex way by even small proportions of certain elements, and in order to co-ordinate practical observations it is important to know which of these elements are present and their amounts. Metallography, the technique of studying polished and etched specimens under the microscope, was founded by Sorby and by Martens some 70 years ago, and led to a very great increase in our knowledge of the structure of metals. Thermal analysis has been used in conjunction with metallography to establish the effective temperatures for heat-treatment and has facilitated the construction of equilibrium diagrams.

As compared with these classical methods, the application of X-ray analysis to metals is a very recent development. Sorby's work remained unnoticed for 20 years; the serious application of X-ray methods to metals has as yet not had half that time to show what it can do. Yet it is already clearly indicated that it will rank with the others as a method of fundamental importance which gives information of quite a new kind. It therefore seems to be very desirable that the exploration of its possible uses for industrial problems should be pushed forward as energetically as possible.

The new information given by X-ray analysis may be summed up as follows:—Metals and their alloys are crystalline, their atoms being arranged in regular patterns. X-ray analysis reveals the nature of the pattern, showing how the atoms are placed relatively to each other. It shows how the pattern varies from phase to phase when different compositions of an alloy system are studied. From the purely scientific point of view, the study of the atomic patterns of alloy phases is providing a new basis for metal-chemistry. The equilibrium diagrams of alloys of two metals have been thoroughly explored by the older metallurgical methods, but the new methods make possible an exhaustive study of alloys of three or more metals. This work is only in the initial stages; there are so many combinations, even if one restricts oneself to the common metals, that it will take a long time to survey the field. However, there are already indications of general laws, and of a theoretical explanation of the crystalline patterns which are formed when the metallic elements are alloyed in different proportions. As far as this goes, the story is very similar to that of the investigation by X-rays of inorganic compounds, minerals, organic compounds, textiles and other materials. The knowledge of atomic arrangement has cast a flood of light upon many old problems of the nature of chemical compounds; it is no exaggeration to say that in many cases, such as the structure of inorganic salts and of minerals, our ideas have had to be completely revised, and much simpler explanations and generalisations have replaced former ones.

The main problem of correlating the mechanical properties of metals with their structure is not solved, however, when we have analysed their crystalline patterns. This is made clear by the following consideration. A study of alloys by X-rays has revealed a large number of crystalline patterns, many of them exceedingly complex. Such complex structures are very interesting as material for a study of metal-chemistry, but the majority of them are brittle and useless for practical purposes. On the other hand, practically all metals and alloys used in industry have one or other of two simple crystalline patterns which are known as "face-centred cubic" and "body-centred cubic." For instance, austenitic structures are face-centred cubic and α-iron is body-centred cubic. Since these patterns are common to alloys which exhibit a wide range of different mechanical properties, we must look for some other feature of structure. X-ray analysis has already indicated the nature of this feature, described in the next paragraph.

The microscope can only reveal structure which is on a scale larger than that of the wave-length of light. Even when pushed to the extreme limit, when magnifications of 2,500 are attained, the details must be on a scale of 10^{-4} cm. if they are to be seen. The crystalline pattern of the metals

is on a scale of 10^{-8} cm.; for instance, the distances apart of neighbouring atoms in the metals chromium, manganese, iron, cobalt, nickel, copper and zinc are between $2{\cdot}4 \times 10^{-8}$ and $2{\cdot}8 \times 10^{-8}$ cm. There is therefore a range of dimensions between the smallest structure visible under the microscope and the scale of the atomic pattern, which is actually more extensive than the range between coarse structures visible to the naked eye and those which can be seen under the highest powers. X-ray analysis conveniently covers the lower range. It takes over just where the microscope can no longer be used, and carries us down to the scale of the atomic structure itself. Further, the structures which are found on the scale between 10^{-4} cm. and 10^{-8} cm. are probably of as much importance to the mechanical properties of the metal as the structures visible under the microscope. In most cases metals and alloys which have valuable mechanical and physical properties are neither in true equilibrium, nor structurally homogeneous, nor perfect crystals. A condition of complete solution of the constituents at higher temperatures may break up by incipient precipitation into regions of different composition, in a manner which depends on rate of cooling or time and temperature of annealing. If we could increase the resolving power some hundred or thousand times, it would be possible to see that the smallest crystals visible under the microscope have further complex elaborations of structure. An alloy may break up, for instance, into alternate sheets of different composition, as described in Part I, such phenomena being quite beyond detection by the microscope. By means of X-rays one can measure the spread and thickness of such sheets, and estimate their composition.

When the crystals of a metal are distorted by cold-work, they are broken up into a mosaic of minute crystals which are not in perfect alignment with each other. Very severe cold-work would appear to reduce the average size of the elements of this crystalline debris to between 10^{-4} and 10^{-5} cm. It will be noted that such dimensions are submicroscopic, and that it is fortunate that we are able to have recourse to X-rays to study the structure of such cold-worked material. Grain size, state of strain and preferred orientation of this interesting condition of the metal can be thus determined. Here we are considering the reason why cold-rolling, cold-drawing and like processes produce their valuable results, and it is very desirable to obtain a clear conception of the mechanism of such processes.

We are as yet unable to explain, even in a qualitative way, how the mechanical strength and other properties of a metal depend either on its structure as revealed by the microscope or on the finer structure inside the visible crystals which is revealed by X-rays. It is, however, well known that certain structures of steel seen under the microscope are correlated with desirable mechanical properties, and that their presence is evidence of success in the treatment the steel has had, whereas other structures indicate undesirable qualities. This is so much a matter of common experience it is hard to realise that such knowledge is purely empirical, and that the properties of the material have in no way been "explained" when an investigator notes a particular structure and correctly infers the quality of the steel. The application of X-ray analysis is already building up a similar body of empirical knowledge, relating the small-scale structures to the bulk properties. There are certain difficulties inherent in the method. We can see structures through a microscope; they have to be inferred from the X-ray results by a rather laborious process of analysis. But experience and training enable an investigator to read an X-ray diffraction picture almost as surely as if he were looking at the actual structures.

In considering the question of mechanical strength, the peculiar nature of a metallic structure must be borne in mind. The atoms of the metal have no direct links one to another. They are held together by a system of electrons common to all the atoms, which can drift through the structure and so make it an electrical conductor. If we imagine a mass of positively charged shot permeated by a negatively charged fluid so that the attraction between shot and fluid holds the whole mass together, we have a working model which may serve as an illustration. The metal atoms can slither over each other, and if the structure is distorted by a relative movement of the atoms the wound can be healed again leaving the structure as sound as before. In contrast to this, the atoms in such solids as quartz and diamond are bound by direct links, which, once broken, are not formed again. The characteristic ductility of a metal, its plastic flow along glide planes, its recrystallisation on annealing and the diffusion of one metal through another at temperatures far below the freezing point, are consequences of the peculiar nature of the metal structure. If the metal atoms can move freely past each other, why has a metal any strength at all? As is well known, the answer to this is that a perfect crystal of any pure metal has so little resistance to deformation that it is still an open question whether the elastic limit tends to zero as perfect purity and regularity are approached. Resistance to shear only exists when the perfection of the crystal is destroyed by cold-working, or when atoms of more than one kind are present. The easy glide along crystalline planes would appear to be blocked in some way by the irregularities due either to the cold-working or to the alloying. In other words, the strength of a metal is not a primary character of its inner crystalline structure, but a secondary character due to the relative orientation of the crystals of which it is composed, or to the ripple-like fluctuations in composition which are the result of heat-treatment and have been described above. Hence the sensitive response of the mechanical properties to heat-treatment and the importance of studying the structures of a sub-microscopic character by X-rays and correlating them with mechanical properties. Hence also the grave difficulties, which have so far defied attempts to overcome them, of forming a satisfactory theory of mechanical strength since it is due to this complex secondary character. The influence on mechanical properties of adding various elements may be direct, in causing ripples in composition (e.g. precipitation-hardening, the effect of carbon in steel). It may be indirect, in that the main function of the added elements is to vary the rate at which such structures are formed so that the necessary heat-treatment becomes a practical possibility (as in many alloy steels). It may confidently be expected that the study of sub-microscopic structures by X-rays will cast light on these problems. A knowledge of structure is essential if progress is to be made with the long-range research of establishing a satisfactory theory of mechanical strength. Quite apart from the final goal, the correlation of the structures with the bulk-properties and the study of the effect of added elements on these structures may lead to the foundation of laws to guide the experimenter as to what elements to add and in what proportion to obtain desired modifications in mechanical or physical properties, and so be of immediate practical importance.

The researches described in the present report may be conveniently classified as follows:—

(*a*) *Study of Phases Formed by Two, Three or More Metals.*—The object in this work has been to survey the different forms of phase structure formed when certain common metals are mixed in different proportions. The metals chosen for the investigation were iron, cobalt, nickel, chromium, copper and aluminium. There are 20 ternary diagrams to be investigated by taking these elements three at a time, and of them the following have been examined over all ranges of composition: Fe-Cu-Ni, Fe-Cu-Al, Cu-Ni-Al, Cu-Ni-Al, Fe-Ni-Cr, Fe-Ni-Co. A complete equilibrium diagram of a ternary alloy involves the establishment of the extent of the various phases at all temperatures. No attempt has been made to do this, or even to fix the precise boundaries of the phase areas at any one temperature. It has been judged more important to make a preliminary and rapid survey of all the various types of phase-pattern which may appear. The same rate of cooling,

20° C. per hour, has been used for all alloys, and it is estimated that the diagrams in this report represent a section of the equilibrium diagram at between 700° and 500° C., below which temperature practically no change takes place with the rate of cooling employed.

The equilibrium diagrams of two metals have been examined in much greater detail. They include Cu-Al, Co-Al, Cu-Ni, Ni-Al, Fe-Al, Fe-Ni, Fe-Cu, Cr-Al. Binary equilibrium diagrams have been much studied by thermal and microscopical methods, and it is possible to compare the previous results with those obtained by X-rays. In some cases (e.g., Cr-Al, Fe-Ni) the X-ray examination has suggested very profound modifications or extensions of the previous diagrams.

The same crystalline patterns recur in different alloy systems, and an important object of the work has been the identification and if possible the analysis of the many types. The face-centred cubic and body-centred cubic structures cover by far the most extensive ranges of composition and, as has been mentioned above, practically all useful alloys are found in these ranges. In addition, there are many highly complex phases, though the majority of these are modifications of one or other of these two simple structures, formed by certain atoms falling out of the structure with a consequent degradation in symmetry.

(*b*) *The Order-Disorder Transformation.*—Certain alloys solidify from the melt with their atoms arranged on a regular lattice, but with a quite random distribution of the atoms of either kind amongst the points of the lattice. At a temperature which may be hundreds of degrees below the melting point, what may be described as a "second crystallisation" sets in. The atoms rearrange themselves by exchanging places until the two kinds are in regular arrangement. The transformation differs from an allotropic change, because in the present case the same lattice points are occupied by the atoms before and after the change, whereas in an allotropic change one type of lattice turns into another. As an analogy, one may picture an array of regularly arranged boxes and an equal number of red and white balls. The high-temperature state is represented by filling the boxes with balls, regardless of their colour, the low-temperature state by rearranging the balls till they form a chequer pattern of red and white. The transformation in β-brass, Cu-Zn, is an example. Now that the evidence for such a transformation is better understood, it has become clear that it takes place in many alloy structures.

Much work has been devoted to the study of this change, and an explanaton is due of the importance which has been attached to it, although its direct bearing on the mechanical properties of alloys may not at first sight be clear. Its interest lies in its simplicity, which enables us to study in detail the movements of atoms in the solid. The change is governed by the relationship between the heat energy of the atoms, the difference in potential energy of the ordered and disordered states, and the "energy-barrier" which has to be overcome in order to cause two neighbouring atoms to exchange positions. The phenomenon provides a very pretty problem for the mathematical physicist, and has attracted the attention of some of the ablest in this country and abroad. The first crude theories only explained its course in a qualitative way, but the latest refinements of theory have been very successful. Extensive experimental investigations have been made by Sykes. The change begins at a critical temperature, but is not complete until the temperature has been further lowered by several hundred degrees. Sykes has studied the degree of order at different temperatures, the output of energy as the change proceeds, the inception of order at nuclei when the critical temperature is reached, their subsequent growth, the effect on the electrical resistance, and the rate of relaxation towards equilibrium. These phenomena resemble the crystallisation of a solid from a liquid, or the growth of one solid phase from another, but they are much simpler because atoms only move from one point to another in a constant lattice. The order-disorder change is an interesting example of a metallurgical change, which has been very thoroughly examined experimentally, and which has received a satisfactory theoretical explanation. Though much remains to be done, the first chapter of the story has been completed, and attention is now being devoted to other problems.

In order to study the change, it has been necessary to construct precision apparatus for measuring the output or absorption of small quantities of energy during the transformation. The apparatus set up by Sykes for this purpose has proved to be very successful, and is now being used to study changes in energy in other transformations such as precipitation-hardening.

The investigations of equilibrium diagrams carried out by Dr. A. J. Bradley, Dr. H. Lipson and their collaborators are described in Part I. In Part II Dr. Sykes has summarised the work which has been carried out under his direct supervision.

Tin and its Uses

THE fifth issue of the above quarterly review published by the International Tin Research and Development Council maintain the high standard of the earlier issues. It contains an article which describes in detail the methods which ensure complete adhesion of white metal linings to bearing shells of various materials, and gives temperatures, strength of acid, etc., for the more difficult cases. A new process developed in the Council's laboratories is discussed for the production of a protective oxide film on tinplate. Although it is so thin that it is invisible, it has been found to give good protection from sulphur staining when tested with canned peas, meats, soups, etc. It may prove an alternative to expensive sulphur-resisting lacquers. Further research is being carried out in collaboration with the appropriate industrial organisations.

Progress in research on high-tin bronzes for condenser tubes is recorded. Comparative tests in circumstances closely approximating to actual service conditions clearly demonstrate the uniformly high corrosion resistance of the tin-rich bronzes. Further particulars of the new "Speculum" plating—first announced in the January issue—indicate that from the point of view of production costs this decorative coating compares very favourably with standard chromium-on-nickel finishes.

Other articles in this issue, which may be obtained free of charge from the International Tin Research and Development Council, Fraser Road, Greenford, Middlesex, England, include an illustrated account of the development and manufacture of the collapsible tube; details of the civilian ration of tinned foods recommended by the British Medical Association, including a tabulation of nutritive values; and an illustrated review of the Council's Report for 1939.

Glass-sealing Alloys

SEALING members for borosilicate glass have been made in the past from austenitic alloys composed of 18 to 25% cobalt, 28 to 30% nickel and 45 to 54% iron. An objection to the latter is the martensitic transformation which may take place at an undesirably high temperature and which may result in an abrupt change in the temperature coefficient during the sealing process. This defect can be eliminated by using sealing elements into which about 0·05% carbon has been introduced by diffusion. This is done, preferably, by heating the elements (cylinders, eyelets, etc.) in a hydrogen atmosphere for 30 mins. at 1,100° C. in presence of a block of graphite, but the same purpose is achieved by heating in a hydrogen atmosphere containing xylene, or by immersion in molten sodium cyanide for 10 mins. at 800° C. Alloys carburized in this manner exhibit a uniform temperature coefficient of $4{\cdot}5 \times 10^{-6}$ down to a temperature well below zero and seal readily with borosilicate glasses of the same temperature coefficient. (U.S.P. 2,189,970).

THE ROMANCE OF CARBORUNDUM.

Carborundum was created by Dr. Edward G. Acheson in 1891.

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The heat generated by the electric current fused the ingredients in the bowl and when the carbon was withdrawn the trained eye of Dr. Acheson discovered some minute crystals adhering to it. These tiny jewel-like bits were found to be amazingly hard and sharp. Some people say that Dr. Acheson thought at first that he had at last made possible the dream of many chemists—man-made diamonds. A few simple tests dispelled this theory but the fact remains that these crystals had wonderful abrasive properties, and were second only to the diamond in hardness and sharpness

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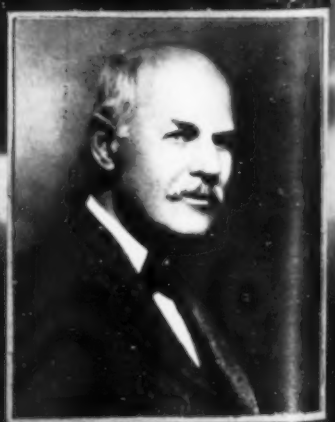


Edward G. Acheson

HEAT TREATMENT
PROCESSES — PRACTICE — PLANT

May, 1940 METALLURGIA Vol. XXII, No. 127

HEAT plays an essential part in the production and fabrication of all metals and alloys from the initial stages of reduction of ores to the manufacture of the finished component or product, in its widest sense ; therefore the term heat-treatment may be applied to all production operations which involve the use of heat. In the narrower and more generally accepted sense, however, heat-treatment refers to processes by which metal products of suitable chemical composition can be modified to produce desired physical properties. This does not mean that heating for various operations which precede heat-treatment proper has no influence on the physical properties of a particular metal when heat-treated ; actually, careless and indifferent heating for the many fabricating operations has great influence upon the subsequent heat-treating and machining operations, and upon the results obtained in service with the finished products. In this section, however, some aspects of heat-treatment, using the term in its accepted sense, are considered, and it is assumed that preceding operations are properly performed. Attention is also directed to some recent developments in equipment.

Fundamentally, heat-treatment does not effect a chemical change in the material ; it effects a change of structure by transformation to establish another phase, by changing the character of the compound or compounds in solid solution. There are exceptions to this statement regarding chemical composition, and these concern heat-treatments developed to produce surface hardening on the material only. Such operations are carburising ; cyaniding and nitriding do effect a change in chemical analysis, since the effect of carburising introduces additional carbon to the surface layer of a steel ; in cyaniding both carbon and nitrogen are picked up, while in nitriding nitrogen is diffused in the surface layer of particular steels.

In the heat-treatment of steels, the main forms in which it is effected are annealing, normalising, hardening and tempering. The temperature of a steel for a full anneal depends on the composition of the steel ; for straight carbon steels the temperature should be very close to 760° C. when the carbon content is 0·8%, but increased temperatures are necessary when the carbon contents are below or above this point. Soaking at the annealing temperature is necessary to ensure that the temperature is uniform throughout the steel. It is important that cooling from the full anneal should be slow to give time for the transformation to take place. The object of this treatment is to soften the steel, refine the structure, and to remove stresses. There are several types of annealing treatment developed to suit particular types of steel or certain production processes.

In normalising, temperatures are usually somewhat higher than for a full anneal, and the transformations are hurried by more rapid cooling. This operation is often used to give the steel the mechanical properties desired in service, thus it is frequently a final heat-treatment, and a wide variety of hardnesses may be produced to meet particular requirements. But steel may be normalised to refine its structure after a forging operation and to make it more uniform, so that any subsequent hardening operation may be effected without perceptible distortion.

Heat-treatment to provide a full hardening operation usually involves a quench from above the critical temperature range, and the more carbon trapped in solid solution by quenching the harder the product. In this condition the steel may be in a highly stressed state ; these stresses can be relieved by a tempering treatment which allows the finely dispersed carbide to coalesce, but tempering generally causes a softening of the steel, which reduces strength, but is compensated for by increased toughness. The tempering temperature will depend upon the degree of toughness desired.

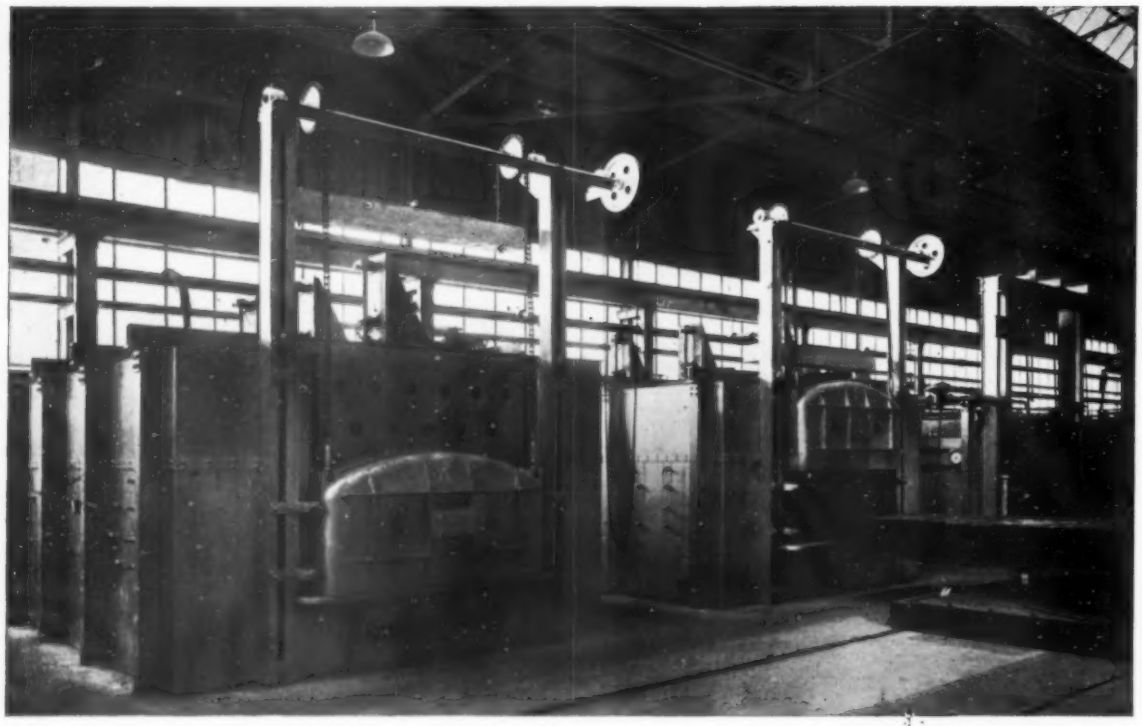
Recent work on the transformation of the solid solution above the critical range in steel, which is composed entirely of austenite, has led to the discovery of a transformation product from which has been developed a process known as austempering. In this process the steel is heated above the critical range, then immersed in molten metal or salt, which cools it at a rate that allows the austenite to decompose at a constant temperature above the martensite range ; the structure, which has been termed bainite, is claimed to give hardness and toughness properties not obtainable in the usual quench and temper method of treatment.

The alloys of aluminium that are subjected to heat-treatment are increasing. In particular, the commercial application of heat-treatment processes to aluminium alloy castings has made great progress in recent years. In this field it has resulted in radical departures in structural designs, revolutionised foundry methods and casting practice, and opened up many new fields of application for castings. Although many of the ordinary aluminium casting alloys are susceptible of improvement as to mechanical properties by heat-treatment, a number of special alloys have been developed in recent years, particularly for use in the production of parts for high-duty service. Such alloys are not only responsibe to heat-treatment, but they also yield much better mechanical properties than the alloys formerly available.

While various heat-treatment processes may be, and are, applied to aluminium-alloy castings, forgings, etc., the type of heat-treatment with which we are concerned here is that involving heating to a suitable temperature, known as a solution treatment, followed by quenching and then ageing or a precipitation treatment. The phenomena of age-hardening are very complex. The main conditions involved in this subject are well known, but the relations between chemical composition, temperature of quenching, temperature and time of ageing, and degree of mechanical deformation during treatment, provide problems which are receiving the attention of research workers in several countries. The effects of age-hardening, first observed in duralumin, are responsible for the production by heat-treatment of properties very greatly superior to those of untreated castings and forgings. Although this form of heat-treatment is associated in practice with alloys of aluminium, there are indications that other alloys display similar phenomena.

Although no strictly new heat-treatment processes have been developed of late, experience with existing methods has been productive of improved procedures. There has been a growing tendency to apply induction hardening and induction heating, salt baths are being employed more widely, especially in the treatment of aluminium alloy components, some firms are showing a preference for gas carburising, while controlled atmosphere furnaces for case-hardening are also receiving attention. A significant trend is the increasing installation of continuous furnace plant for heat-treatment operations.

GIBBONS FURNACES



The above illustration shows a battery of Gas Fired Muffle Furnaces for Annealing Light Alloy Sheets.

Reliable results sought in heat-treating practice depend upon the proper combination of the man, the furnace, and the material. Good material is entitled to proper treatment in good furnaces, and both should have the services of good men.

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The Heat-Treatment of Light Alloy Castings

By H. G. Warrington

Production Metallurgist, Messrs. High Duty Alloys, Ltd.

Practical aspect of the heat-treatment of light alloy castings are reviewed. The various groups of heat-treatable light alloys are briefly discussed and factors affecting heat-treatment operations are considered; particular attention is directed to quenching. Changes in structure are considered and attention is given to furnace equipment. Essentially, it embraces the experience of the author given in a recent paper before the London Section of the Institute of Metals, which emphasised the need for an understanding of the general metallurgical principles of light alloys for the successful running of a heat-treatment department responsible for the treatment of a wide variety of materials and components.

THE broad outlines of heat-treatment application have been unaffected by pure research, they remain essentially the same as when the phenomenon of age-hardening of duralumin was first discovered. They are, firstly, a solution treatment, which is given at a temperature as near as possible to the melting point of the alloy eutectic, followed by rapid cooling in a quenching medium for retention of the structure obtained at this temperature; and secondly, an age-hardening treatment, which may be at air temperature or slightly elevated temperatures. Whatever variations of this treatment are practised, such as variations in the rate of heating, rate of quenching, or subsequent annealing, are dictated by a knowledge of the ability of the alloy concerned to attain equilibrium, the stability of the solid solution, and practical considerations of quenching stresses or subsequent application as an engineering component.

There is scope for considerable development in the knowledge of critical rates of quenching for various alloy systems, of the effects of quenching stresses, and means for their reduction in effect, and also of the rates of diffusion of solid solution segregates in heterogeneous cast materials. In practice this knowledge is forced upon us when a casting cracks after quenching, and a better rate of quenching is found by rule of thumb. Similarly, if a casting is cracked on heating, it is assumed that either severe casting stresses existed, which have been locally too rapidly released, or that the rate of heating was such that eutectic segregates have not gone into solution at a similar rate, causing local weakness.

Exact data on this subject would be of immense benefit to industry, and would, without a doubt, enlarge the scope of the application of castings and casting alloys.

Heat-treatable Alloys

Following Wilms' discovery of the heat-treatment of of duralumin it was a logical development to apply the same reasoning to cast aluminium alloys, and in the United States, and on the Continent, the binary alloy containing 4% copper was first developed on these lines. In this country, however, materials were used in the "as cast" condition for a much longer period, commercial application of heat-treatment commencing with the use of the N.P.L. "Y" alloy for castings, which was for many years confined to pistons.

TABLE I.

Trade Mark.	Specification.	Major Constituents.						Solution Treatment.	Ageing Treatment.
		Cu.	Ni.	Mg.	Si.	Fe.	X.		
Group I.									
Alpax Beta	D.T.D. 240	—	—	0·6	11·0	—	0·6 Mn	None	16 hours, 160° C.
Alpax Gamma	D.T.D. 245	—	—	0·6	11·0	—	0·6 Mn	4 hours, 530° C.	16 hours, 160° C.
N.A. 125	D.T.D. 276 / D.T.D. 298	1·2	—	0·5	5·0	—	0·2 Ti	12 hours, 520° C.	10 hours, 160° C. (D.T.D. 276 only)
Hiduminium 40	Admiralty	—	—	0·7	2·0	—	0·7 Mn	5 hours, 520° C.	15 hours, 160° C. } See later
Hiduminium 42	Admiralty	—	—	0·7	5·0	—	0·7 Mn	5 hours, 520° C.	15 hours, 160° C. } later
Group II.									
Hiduminium RR 50	D.T.D. 133B	1·6	1·0	0·10	2·5	1·0	0·17 Ti	None	10 hours, 165° C.
Hiduminium RR 53	D.T.D. 131A	2·2	1·0	1·5	1·2	1·0	0·1 Ti	4 hours, 530° C.	15 hours, 165° C.
Hiduminium RR 53C	D.T.D. 309	1·6	1·0	0·5 max.	2·5 max.	1·0	0·1 Ti max. Cd	6 hours, 530° C.	15 hours, 165° C.
Aeral A	D.T.D. 294	2–4	—	0·5	2·5	—	2·5	6 hours, 495° C.	16 hours, 165° C.
Ceralumin B	D.T.D. 287	1·5	1·3	0·1	2·0	1·0	0·15 Ce	None	16 hours, 165° C,
Ceralumin C	D.T.D. 255	2·5	1·3	0·8	1·2	1·2	0·1 Ce	6 hours, 530° C.	16 hours, 175° C,
Ceralumin D	D.T.D. 250	2·5	1·3	0·8	1·2	1·2	0·1 Ce	6 hours, 530° C,	None.
Y alloy	B.S.S.L. 35	4·0	2·0	1·5	—	—	Ti	6 hours, 515° C.	2—10 hours, 100° C.
Group III.									
N.A. 222	D.T.D. 269	4·4	—	0·2	0·8	0·6	0·2 Ti	12 hours, 510° C.	20 hours, 155° C.
N.A. 225/91	D.T.D. 298	4·4	—	—	Max. 0·9	—	0·2 Ti	16 hours, 535° C.	None.
N.A. 225/92	D.T.D. 304	—	—	—	—	—	—	16 hours, 535° C.	20 hours, 165° C.
N.A. 226	D.T.D. 361	4·4	—	—	Max. 0·9	—	0·2 Ti.	16 hours, 535° C.	12 hours, 165° C.
Group IV.									
N.A. 350 / B.A. 29	D.T.D. 300	—	—	10·0	—	—	—	16 hours, 420° C.	None.

American automobile manufacturers establishing plant in the British Isles specified the materials to which they were accustomed, and the 122 alloy, containing 12% copper with additions of iron and magnesium, was introduced for pistons, which were heat-treated to give maximum hardness. From 1928-1930 the Hiduminium RR series of alloys was introduced in an attempt to specialise individual alloys for special purposes, and the problem of heat-treatment was given more thought than previously.

Another major development was the reintroduction of the binary aluminium-magnesium alloys, first used by the Westinghouse Electric Co. in U.S.A., but with a heat-treatment technique giving very high ultimate stress and ductility. Other copper-free alloys are the Alpax group, which, with the addition of magnesium, will respond to heat-treatment whilst still retaining their ease of casting, and the magnesium-silicide hardening type such as the Hiduminium Anticorodal series, Hiduminium 40 and 42.

From the point of view of composition, heat-treatment temperatures, and to a certain extent mechanical properties, the alloys can be grouped as shown in Table I. The alloys enumerated are those listed in official standard specifications, and are presumably those enjoying the widest commercial use.

In Group I are the alloys whose major constituent is silicon, or magnesium-silicide, which are fluid in casting, and rely for their heat-treatment properties on the solution and precipitation of the compound Mg_2Si. They enjoy a wide use for general stressed castings, and the Hiduminium 40 and 42 of the Anticorodal series are specified for corrosion-resisting Admiralty castings.

Group II are far more complex and exhibit heterogeneous structures which are apparently little changed by solution heat-treatment owing to the presence of hardening constituents of the iron group, which can be traced in all the intermetallic compounds microscopically visible. The hardening of "Y" alloy is claimed by Archbutt and Rosenhain to be due to a complex Cu-Ni-Mg compound, and presumably a similar effect could be traced in all alloys of this type.

These alloys are used in some measure for general castings, particularly those of lower magnesium content, but especially for applications where strength at elevated temperatures is required, such as cylinder heads and pistons for internal-combustion engines. The internal-combustion engine is one of the greatest outlets for aluminium alloys, and where one of these alloys is essential for certain of its components, it is of benefit to production to use the same alloy for auxiliary castings. Hence the use of this type of alloy has grown enormously in the last five years, and accounts in some measure for the variety of almost exactly similar compositions marketed by competitive interests, which is in itself a tribute to the undeniable properties of the alloys as a group type, and the interest they maintain in commercial development and research.

Group III are alloy variants, or heat-treatment variations, of the binary 4·0% copper-aluminium alloy. Hardening relies on complete solution of the $CuAl_2$ compound giving a strong ductile casting useful for general engineering purposes, but as yet not used to any great extent for intricate castings or for use at elevated temperatures.

Group IV as yet contains only one alloy, the binary 10% magnesium-aluminium alloy. Correctly cast and heat-treated, properties approaching those of wrought materials are claimed, and it is used for highly stressed components operating at air temperature, such as dredger-bucket parts and large levers. The alloy involves some difficulty in casting and heat-treatment, but successful application will undoubtedly enlarge both its use and the number of alloys in the group.

General Heat-Treatment Considerations

In a general tabulation of alloys in this manner, certain indication of the sensitivity of castings during heat-treatment may be obtained by a study of the published specifications. The specifications covering Group I state quenching should take place simply in boiling water or cold water. Defective material by quenching, i.e., cracking, is not to be expected therefore, the worst defect being a certain amount of distortion. It is anticipated from this that the alloys easily obtain conditions of equilibrium, and change rapidly with change in temperature. Quenching, then, must be severe to retain solid solution of the hardening compounds, and distortion, owing to the ductile nature of the alloys at the quenching temperature, will replace cracking.

In Group II the quenching media specified are water, boiling water, and water or oil. Some attempt at controlling the quench is observed to have been necessary even during the development stage of some of these alloys. Group III specifies that the water for quenching shall be between 80°—100° C. In Group IV the greatest precautions are taken in that the castings must be quenched in oil at 150° C., and, if necessary, the temperature of the castings should be reduced from the solution-treatment temperature of 430°—385° C. before quenching, indicating a greater property of retention of solid solution. The converse will be expected, therefore, that greater difficulty in obtaining solid solution will be noticed. This is apparent, in that the times for solution treatment gradually increase from four hours to not less than 16 hours reading down the table.

The sensitivity at the moment of quenching, which will induce quenching stresses, distortion and cracking, will increase with the size and complicity of the casting. This problem is less disturbing for castings than for forgings, as in the former case, if properly conceived, a minimum of machining is to be done, and, consequently, minimum disturbance of residual stresses. The distribution of stress to be expected from quenching should be known to some extent on experience, and may affect the casting technique. A simple experiment in quenching a plain cylinder of length equal to three times the diameter can be used to demonstrate stress effects. A saw-cut in the side will close in on the saw and eventually impede its progress. On the other hand, a longitudinal cut will tend to open up, the block eventually splitting before the cut is completed if the material is of maximum hardness. Heavy cylindrical bosses should therefore be cored out, and levers or lugs attached to heavier sections should be cast with a tie-bar to keep them in position during treatment.

The presence of internal stress, due to quenching, cannot be tolerated on many castings, such as engine cylinder blocks or cylinder heads, owing to the intricacy of the machining and the temperature variations in service which may upset the residual stresses and cause distortion, throwing bolt and stud holes out of alignment and causing ovality of bores. For these purposes three alloys are used which are given a low-temperature precipitation treatment only, being those specified under D.T.D. 133B, D.T.D. 287 and D.T.D. 240, respectively. After solidification of the liquid metal it passes through the same temperature range as that attained by the solution treatment. As cooling is never sufficiently slow to obtain equilibrium conditions there is a certain retention of solid solution on cooling in the mould, and a subsequent precipitation treatment will give a definable improvement in mechanical properties. At the same time a stabilising effect is obtained, in that casting stresses are reduced. As these alloys rely more for their properties on the heterogeneity of structure than the complete solution of constituents, the properties obtained are suitable for engineering requirements and are less likely to be affected by operation at slightly elevated temperatures. An alloy which depends upon complete solution for its mechanidal strength suffers greater loss on annealing, when the alloying constituents are thrown out of solution, than the more complex type containing insoluble intermetallic compounds, which are little affected by heat-treatment, and the consideration of the heat-treatment effects is of assistance in choosing an alloy for operation at elevated temperatures.

The whole question of heat-treatment of castings for operation at elevated temperatures has been the subject of controversy in industry for many years, and an authoritative decision has not yet been arrived at to cover all cases. Opinion has been expressed that if a component, such as a piston or cylinder head, is to be annealed in service, it is useless to heat-treat it at all. Another and very sound opinion is to heat-treat the component and to anneal it at its maximum operating temperature. A piston, however, is not completely annealed in service, the crown only being appreciably softened. Designers wish to take advantage of the maximum obtainable strength in the gudgeon pin bosses which, normally, retain their hardness over their full life. If the piston is fully heat-treated the annealing of the crown upsets the stress distribution of the casting and distortion occurs, which is evidenced as scuffing or excessive local wear. It is on problems of this nature that the heat-treatment technician must collaborate with the user and complement theoretical considerations with details of performance.

An allied problem, in that it involves departure from obtaining maximum theoretical hardness and strength, is that of large castings or castings involving rapid changes in section.

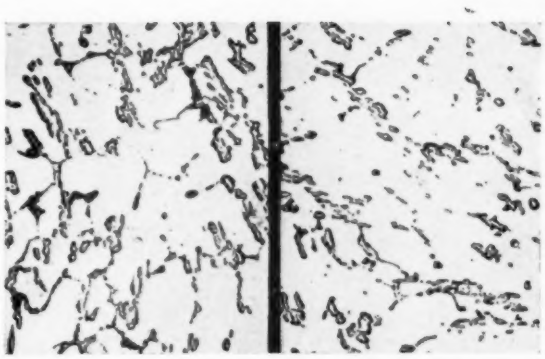
The rapid quenching in cold water of a large casting induces variations in rate of cooling that will cause quenching cracks, visible distortion and residual stresses. Such castings must be considered for modification of the normal specified treatment, and some development work is necessary on typical castings so that an alternative specification can be offered when the occasion arises. The alternative quenches are, cold water, boiling water, oil, heated oil, air blast, and still air. These are not necessarily in order of reduction in effectiveness, as under certain conditions, depending on the section of the casting, the relative volume of the quench and convection or circulation, boiling water can effect a gentler quench through the critical range than hot oil or a fierce air blast.

Under certain conditions it would appear that with a boiling water quench a protective cushion of steam forms around the component until its temperature has been reduced to something approaching 100° C. Where the stresses in the casting are likely to exceed the strength of the material at the moment of quenching, it is desirable to reduce the temperature of the furnace to one at which the casting is strong enough to withstand these stresses. The effects of this temperature reduction, and the delay in the rate of quenching must be fully understood, however, as the resultant properties will depend on the ability of the material to retain the solid solution condition under comparatively slow rates of temperature change.

An example can be given of the results obtained on an alloy given in Group I, namely Hiduminium 40, which is hardened by addition of magnesium-silicide only, the heavy metals being absent in order to give a high order of corrosion resistance. A treatment was sought for very large castings of complicated section, and preliminary experiments suggested that the following series of operations should be compared:

(1) Solution treatment, 5 hours at 520° C. Quench in boiling water. Naturally age five days.

(2) Solution treatment, 5 hours at 520° C. Quench in boiling water. Age 16 hours at 160° C.



As cast. Heat-treated.
Fig. 1.—Micro-structures of alloy D.T.D. 131A. × 100.

(3) Solution treatment, 5 hours at 520° C. Cool in furnace to 480° C. Quench in whale oil and naturally age five days.

(4) Solution treatment, 5 hours at 520° C. Cool in furnace to 480° C. and quench in whale oil. Age 16 hours at 160° C.

A number of large castings were heat-treated under production conditions according to this programme, and eight test-pieces cut from them from parts of widely varying section. In the preliminary tests the delayed quench in whale oil established that freedom from distortion and cracking could be obtained, and the mechanical properties obtained from the series of test-pieces demonstrated the effects on the efficiency of the heat-treatment. They are summarised at foot:

It is observed that satisfactory properties are obtained in all cases except with the delayed oil quench and ageing at 160° C. In this case the proof stress and ultimate stress are very close, there is a lack of ductility and the dispersion of results is greater, there being a range of almost 4 tons per sq. in. on the highest and lowest of ultimate stress. It is apparent that incomplete solution exists, which will vary with the differing cast structures in different parts of the casting causing diversion of results, and that artificial age hardening after a delayed quench is, in this case, unsatisfactory. In the naturally aged condition this effect is not felt and increased ductility is shown to be present, which gives a satisfactory treatment for the type of casting discussed.

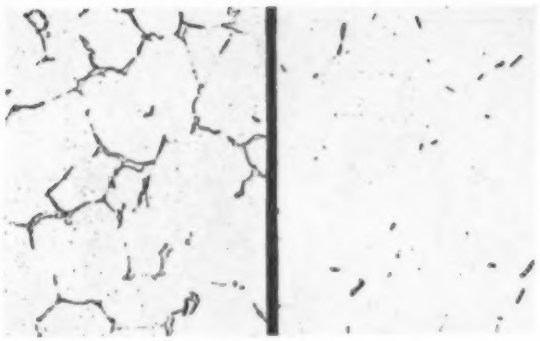
Micro Structure Changes

The difference between the alloys of Group II and the simple solid solution type are illustrated by photomicrographs of the alloy to D.T.D. Specification 131 A in the "as cast" and heat-treated conditions (Fig. 1). Very little difference can be observed between the two structures from a superficial glance, although careful examination, by one accustomed to the features of the alloy, will reveal solution of the magnesium silicide and copper constituents. The main skeleton remains, however, as it is formed by the iron- and nickel-bearing compounds which maintain the strength of the material at elevated temperatures. For comparison, the structures of material to D.T.D. 304 are shown in Fig. 2. In this case almost complete solution of the $CuAl_2$ constituent has occurred, giving a typical solid solution structure.

The most dangerous feature liable to be associated with

TABLE II.

	Solution Treated, Water Quenched and Naturally Aged.	Delayed Oil Quench and Naturally Aged.	Solution Treated, Water Quenched, Aged 16 hours, 160° C.	Delayed Oil Quench and Aged 16 hours, 160° C.
Limit of prop.	4—5 tons/in.²	4—4·6 tons/in.²	6—8 tons/in.²	—
0.1% proof stress	7—7·6 „	6·5—8·0 „	12·5—14·0 „	11—15·0 ton/in.²
Ultimate stress	11·75—12·25 „	10·5—12·25 „	14·5—16·0 „	11·5—15·35 „
Elongation % on 2 in.	3—4	2·0—4·0	1·0—1·5	0·5—1·5
Brinell hardness	64—87	63—85	80—98	76—87



As cast. Heat-treated.
Fig. 2.—Micro-structure of alloy D.T.D. 304. × 100.

heat-treatment is that of overheating. This may occur through failure of automatic temperature regulators, or, what is more difficult to discover, by accidental displacement of the registering or controlling thermocouples, which then no longer give a true reading of the actual charge temperature.

The effects of overheating are first seen in the occurrence of excessive distortion, accompanied in some instances by cracking or blistering. Fusion of the eutectic constituents weakens the casting intrinsically and renders the material extremely brittle. Fortunately, the symptoms are easily recognised, a fracture test showing discoloured areas where internal cracks have formed, the material breaking under light impact. The micro structures obtained are characteristic, the examples shown in Fig. 3 being material to Specification D.T.D. 131A, heated progressively at 545° C., 550° C. and 555° C., respectively. Complete redistribution of the complex eutectics, following fusion, gives a characteristic appearance from which the approximate extent of the overheating can be estimated.

Failure to respond to heat-treatment by increase in tensile properties is an elusive feature, and may be caused by casting defects. The specimen illustrated in Fig. 4 is a severely chilled die casting in alloy to D.T.D. 309, in which internal shrinkage occurs. Tested in the as-cast condition normal tensile properties are obtained, but no improvement is shown on heat-treatment. The shrinkage is insufficient in itself to reduce the strength of the material, but is indicative of eutectic segregation, there being impoverishment of the necessary constituents in this area to form the correct solid solution. This feature, however, is more likely to occur on magnesium-base alloys, where it is a serious problem, and is comparatively rare on aluminium alloys.

Furnace Equipment

The heating media generally obtainable for the purpose of heat-treatment are producer gas, coal gas, fuel oil and electricity. With direct heating it is found that, in general, the higher the calorific value of the fuel the more difficulty is experienced in temperature control. Hence pre-mixers are used in many cases or the heat energy transformed to electrical energy for ease of application. Alternatively, the fuel may be burnt in radiant tube heaters, the heat being transferred to air that is circulated rapidly over the tubes and the work. Molten salt is also used as the medium for heat transfer, flattening out rapid changes in temperature and transferring the heat to the work in the most efficient way.

The first and major item in the specification of a furnace for the heat-treatment of light alloys is that the heat interchange shall be rapid so that as small a temperature difference as possible exists between the heating medium and the castings being treated, thus eliminating "hunting" or wide temperature variations during control. This is achieved by means of air circulation, which should be as rapid as possible consistent with fan design. The pit type furnaces, illustrated in Figs. 5, 6 and 7, are typical electric resistance heated furnaces used for this type of work. A high air speed is achieved, and has been checked to be of the order of 20—30 ft. per sec. A point worth noting in checking this type of furnace is that it should be done with a full load that will split up the air stream, otherwise false results are obtained, strangely enough in some cases giving an apparent reduction in air speed with an empty furnace. One furnace is shown with the lid removed to indicate the position of the thermo-couples. Although the temperature gradient throughout such a furnace is limited under good conditions to within ±2° C., bad packing can cause an air lock, and it is good practice to ensure that the couples extend to the centre of the charge.

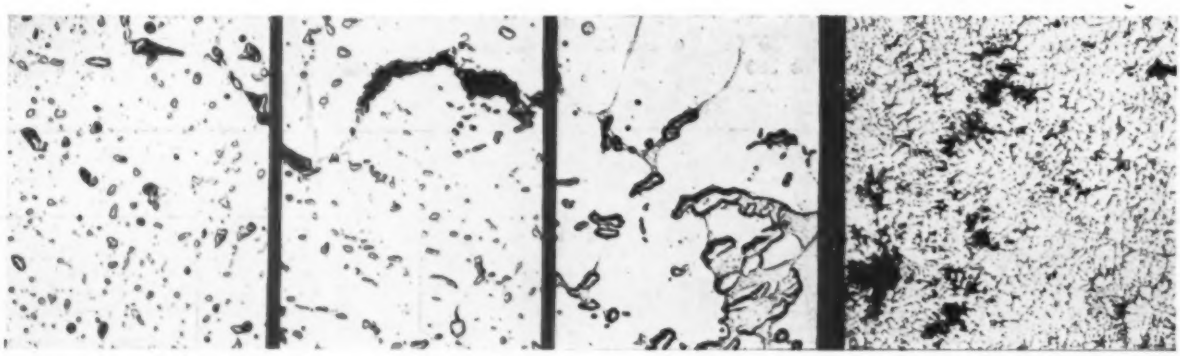
It is essential that individual castings are well supported, as the strength at the solution treatment temperature is low, there being a liability that unsupported parts will sag under their own weight and collapse. In some cases jigs are necessary to obtain the requisite freedom from distortion, as in the case of castings it is unwise in general to attempt any resetting after treatment.

For the solution treatment of magnesium-base alloys atmospheric control is necessary, as, at the high air speeds in an air furnace, combustion occurs at the temperature of operation with almost explosive violence. A simple way to achieve this is to use oil or gas fuel in a fully recirculating furnace. The type illustrated in Fig. 8 embodies three heating chambers fed from a single heating unit. Combustion takes place in the external combustion chamber, and is circulated by means of a fan and returned. The recirculation of combustion products makes the control of the atmosphere composition a simple matter, increases the efficiency of the furnace, and gives a lower combustion chamber temperature.

Salt baths, using a mixture of chromates as the heating medium, are known to be used for the treatment of magnesium alloys, but are rather expensive, there being a high

Fig. 3.—Micro-structures of alloy D.T.D. 131A × 100.
Overheated to 545° C. Overheated to 550° C. Overheated to 555° C.

Fig. 4.—Micro-structure of D.T.D. 309. Chill cast, showing inter-dendritic shrinkage. × 100.



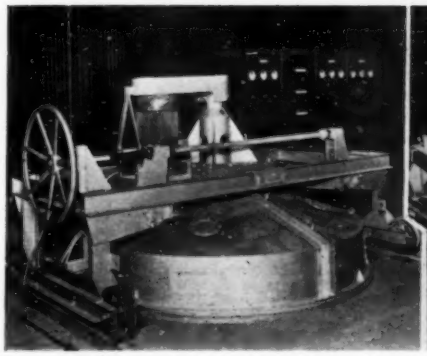


Fig. 5.—Pit type electric furnace and control panel.

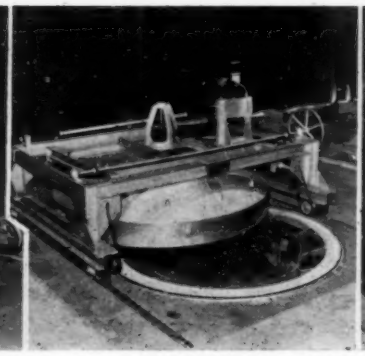


Fig. 6.—Pit type electric furnace and recorder.

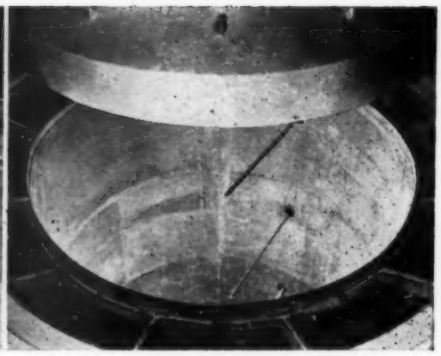


Fig. 7.—Internal view of pit type furnace showing thermo-couples.

salt loss, lack of cleanliness in operation, and a danger of chrome poisoning to the operators. Nitrate salt baths, which are used for aluminium alloys, must not on any account be used for magnesium, owing to the serious risk of explosion.

Nitrate salt baths offer a means whereby at low initial cost satisfactory heating, easy to control, is obtainable for aluminium alloy castings. For very thin section unsupported castings with delicate fins or lugs, an added advantage is that the alloy has a relative density of 1·6 when immersed in salts, which reduces the danger of sagging under its own weight.

There have been occasions, on the Continent, when serious explosions have occurred through the use of molten nitrate salt baths, and minor reactions have been known to occur in this country, in the latter case, fortunately, with no worse result than a hole being burnt in the bottom of the container and the loss of the salt. It is customary, therefore, when designing a salt bath layout to include a safety pit in which the salt can be emptied, to avoid it spreading over the shop floor. The salts concerned have always been either the eutectic or the 50–50 mixture of the alkalie nitrates. It came to the notice of the author's firm that a proprietary salt was being marketed in this country, believed to be basically sodium nitrate with an addition of approximately 10% of potassium nitrite. It was believed, through observation, that the cause of the spontaneous decomposition of the salt was due to local overheating of the container, and the following check test was carried out.

Two model salt baths were constructed of welded mild steel and, to give the worst possible heating conditions, were fired by means of oxyacetylene welding torches, each adjusted to the same flame size and gas consumption. The two salts were tried side by side, and in the case of the 50–50 nitrate mixture, as soon as a temperature of 400° C. was registered, a reaction was seen to commence at the spot where flame impingement occurred. A spiral of reaction product began to rise from the steel bottom, together with evolution of nitrous fumes, and in less than 30 seconds the temperature rose to 650° C. A hole then appeared from the inside and further reaction ceased by loss of salt. In the other case heating was continued for 20 minutes after obtaining 400° C., and when a temperature of 700° C. was registered a hole was melted through from the outside by the action of the welding flame alone, there being no chemical action discernible.

It is thought that where serious explosions have occurred with the 50–50 nitrate mixture the reaction has increased in violence and temperature, and, if the bottom of the container has not been pierced, eventually involves the whole mass of the bath. If local overheating is avoided, however, and a periodic inspection made for scaling and sludging, there should be little danger from this source.

The same general principles apply to age-hardening furnaces as to those for solution treatment, and similar furnaces may be employed. However, it is less costly owing to the lower temperatures to design furnaces for the purpose. The one shown in Fig. 9 has an air speed of approximately 700 ft. per min, and is controlled to a maximum temperature variation over the chamber of 5° C. Combustion is in a separate chamber, and the gaseous products are recirculated by means of a blower fan. These furnaces have developed industrially from enamelling ovens, considerable refinement being needed for the closer temperature control required.

Fig. 8.—Oil-fired three-chamber controllable atmosphere furnace.

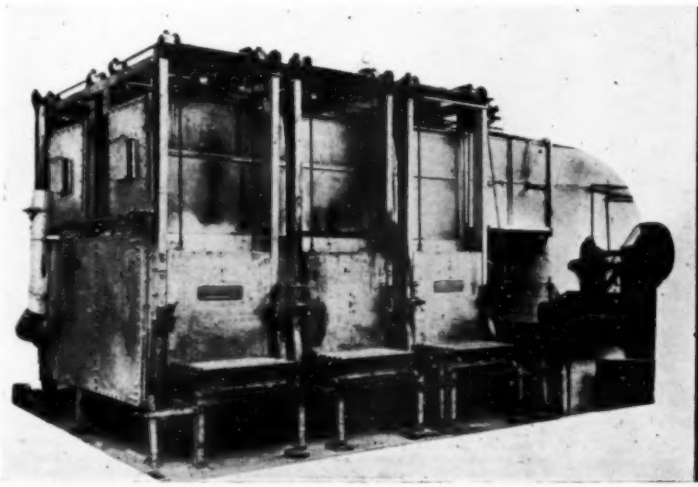


Fig. 9.—Battery of gas-fired ageing furnaces.

Carburisation with Special Reference to the Use of Solid Carburising Agents

By F. W. Haywood, Ph.D., F.I.C.

Without doubt, one of the most important processes carried out in every heat-treatment shop dealing with ferrous materials is the process of carburising, and not infrequently too little attention is paid to this process. This short article is intended primarily to give a number of practical points in connection with carburisation, using solid carburisers, termed in the trade "box carburising," although mention is made of the use of liquid and gaseous carburisers.

THE process with which we are concerned—namely, carburising—is the movement of carbon into iron and steel, which is carried out with the object of obtaining an article with a hard surface and a tough core or interior. In the absence of a gas, it has been shown quite conclusively that solid carbon does not diffuse into iron and steel when heated to temperatures in the region of 900°–1,000° C.—that is, for effective carburisation the carbon must be presented to the steel either as carbon monoxide or a hydrocarbon. Such gases when in contact with the surface of a heated piece of steel are decomposed or split up to give atomic carbon, which is first absorbed at the surface and then diffuses into the iron or steel. This causes the concentration of carbon in the steel at the surface to rise, whilst a little below the surface the concentration is that of the original steel. Provided the temperature of treatment is above the critical range for the steel used, the carbon will migrate from the surface layer inwards and a concentration gradient is set up. As this carbon moves forward into the steel, more carbon is being provided from the carburising source. The relative ratios of the two processes control the depth of penetration of carbon, the concentration gradient of carbon and the maximum carbon content obtained. The factors just mentioned are also controlled by the rate of diffusion of carbon that is the diffusivity constant, the temperature of treatment and the carburising activity of the atmosphere employed. The temperature of treatment is one of the most vital factors controlling and influencing the rate of diffusion and the activity of the atmosphere; this latter factor, generally due to a change in composition of the atmosphere having the effect of raising the maximum carbon concentration, increasing the concentration gradient and so increasing the depth of penetration.

Without doubt historically, the most important solid diffusion process was that of carbon enrichment. Turning to scientific investigations, this subject of carburisation has interested a large body of men. In 1798 Clouet[1] heated an iron crucible containing a diamond, as a result of which a small quantity of steel was obtained. In 1815 Pepys[2] heated an iron wire electrically in contact with diamond dust and converted the wire into steel. Other investigators, such as Margueritte,[3] in 1865 carried out experiments on the carburisation of iron in diamond powder, graphite, and sugar carbon, replacing the air surrounding the wire and carburising compound by pure hydrogen, as a result of which he concluded that cementation occurred as the direct result of the absorption of solid carbon alone, without the aid of any gaseous intermediate compound. The first critical investigation, to determine whether solid carbon would diffuse into heated solid iron was made by Roberts-Austen[4] in 1889. He repeated Margueritte's experiment with improved apparatus, and found when using diamond dust that carbon had diffused into the iron only at the points of contact. He concluded that either carbon entered iron in the solid state, or at most minute traces of gaseous substances sufficed to effect the transference. Experiments carried out by Guillet[5] in 1904 show conclusively that carbon alone cannot react by simple solution with iron, and many investigators since that time have proved this to be true. Attention was next focused on the use of carbon monoxide by Margueritte,[6] Graham,[7] Charpy,[8] and Giollitte,[9] and it was established definitely that carbon monoxide had strong carburising properties.

Courtesy of Wild-Barfield Electric Furnaces, Ltd.

Fig. 1.—Typical furnace installation for carburising and reheating.

Use of Solid Carburisers

By far the greatest quantity of steel carburised in this country and elsewhere is by the use of solid carburisers—that is, materials rich in carbon—and the process is commonly referred to as "box carburising." The parts to be carburised, which, if not already in a stress-free condition, may have to be normalised or quenched and tempered prior to carburising; are packed or embedded in carburising compounds in suitable heat-resistant boxes. These compounds consist of carbon in some form or other, usually charcoal of certain special varieties, together with "energisers," such as barium carbonate, which are bonded together with oils or molasses as binders and then the whole formed into suitable sized pellets. The principle behind pelleting is to retain the energiser in close contact with the charcoal and so avoid dustiness when the charge is removed, and to avoid settling out of the $BaCO_3$. Charred leather, bones and the like used to be old-time carburisers greatly in demand, and it is more than likely that the energising action of the ash of such materials greatly contributed to their success. They are seldom used nowadays, having been replaced by compounds consisting essentially of the constituents previously mentioned. It would be well at this juncture to inquire into the action of energisers in carburising compounds and also the mechanism underlying box carburising. Materials generally used as energisers consist of carbonates of the alkali and alkaline

1 Clouet: See Guyton de Morveau. *Annales de Chimie*. 1799. Vol. xxxi, p. 328.
2 Pepys: *Philosophical Transactions of the Royal Society*. 1815. P. 371.
3 Margueritte: "Sur l'acieration." *Annales de Chimie et Physique*. 1865, Vol. vi, p. 55.
4 Roberts-Austen: *Nature*. 1889. Vol. xli, p. 13.
5 Guillet: "La cementation des aciers au carbone et des aciers speciaux." *Memoire de la Société des Ingenieurs Civils de France*. 1904. No. I, p. 177.
6 Margueritte: *Comptes Rendus*. 1859. Vol. lix, pp. 185, 518, 726.
7 Graham: *Philosophical Transactions of the Royal Society*. 1866. P. 399.
8 Charpy: *Comptes Rendus*. 1903. 2me sem., vol. cxxxvii, p. 129.
9 Giollitti and Tavanti: "Ricerche sulla fabbricazione dell'acciaio cementato II Cementazione di acciai a bassa tenore die carbonio, coi gas alla pressione atmosferica e a pressione ridotta." *Gazzetta Chemica Italiana*. 1908. Vol. xxxviii, Part II, p. 309.

earth metals—that is, sodium carbonate, potassium carbonate, calcium carbonate, and barium carbonate, the one in most common usage being barium carbonate. Carburisation proceeds exclusively by the action of carbon monoxide (CO) on the steels being heated. In carburising, however, with CO it is vitally important to eliminate the carbon dioxide (CO_2), formed as fast as it is produced, and this is done by supplying solid heated carbon which reacts with the CO_2 to form fresh CO as follows :—

$$C + CO_2 \rightleftharpoons 2\,CO \quad . \quad . \quad . \quad . \quad (1)$$

This reaction is a reversible one, and will stop only when the CO/CO_2 ratio becomes sufficiently high, but fortunately the presence of a large excess of carbon as the heated carburising compound prevents this and maintains a constant supply of CO. When energisers are used, as, for example,

Courtesy of Wild-Barfield Electric Furnaces, Ltd.

Fig. 2.—Carburising furnace showing box entering the furnace. A tempering furnace and various quench tanks are also shown.

barium carbonate $BaCO_3$, the richness of the CO is further enhanced because at carburising temperatures 900°–1,000° C. such compounds decompose in the presence of excess carbon to give further CO, as :—

$$BaCO_3 + C \rightleftharpoons BaO + 2\,CO \quad . \quad . \quad . \quad (2)$$

Also any CO_2 which does not react as shown by equation (1) will combine with the barium oxide produced in equation (2) to reform more energiser $BaCO_3$ as :—

$$BaO + CO_2 \rightleftharpoons BaCO_3 \quad . \quad . \quad . \quad . \quad (3)$$

Thus the presence of energisers serves a twofold purpose, the enrichment of the atmosphere by CO and the removal of undesired CO_2 to form in turn fresh CO. Another explanation of the functions of an energiser is the reversible formation of CO_2 as given in equation (3), and the conversion of this CO_2 reacting with hot C to form more CO. This latter explanation is the one most commonly given, given, but the explanation set out in detail above—that is, the displacement of the CO/CO_2 equilibrium—is more satisfactory.

Other materials may be used as energisers for special purposes when box carburising, as, for example, the use of sodium or potassium ferrocyanide when a very thin hard case is desired. Pulverised coke is often used to form part of the carbon, but whilst replacing hard-wood charcoal, it can be considered as a dilutant only in the absence of an energiser. Many solid carburising compounds contain sodium carbonate, but the sodium oxide which is formed in a similar manner to the barium oxide, as indicated in equation (2), has a more destructive action on carburising boxes.

Used or spent carburising compound should be allowed to stand in air to " regenerate " before being mixed with fresh carburising compound for re-use. The usual explanation offered for this regeneration is that the BaO formed—when using $BaCO_3$ as energiser—must be converted back by absorption of atmospheric CO_2 to $BaCO_3$, but this seems very unlikely. The most probable explanation is the actual absorption of air into the interstices of the charcoal and energiser to replace that removed and converted into CO during the process of box carburising.

The amount of energiser added to carburising compounds varies from 5 to 20%, and excess over an optimum value does not give enhanced carbon cases.

One of the most important factors in box carburising, having, of course, selected the most suitable compound and energiser for the particular work in hand, is the packing of the box. It is essential that free access of carburising gas should take place to all parts of the work to be carburised, and it is customary to pack so that when the carburiser settles and shrinks it still completely envelops the charge. The box cover should be a good tight fit and well luted with clay so that loss of carburiser by actual external combustion is avoided. The size of box used has an important bearing upon the quality of the work turned out, and it is axiomatic that the box should be no larger than is absolutely necessary, chiefly on account of time and consequently temperature lag of the interior of the box. Furthermore, it should, if possible, be narrow in one dimension so that the heat may have a chance to penetrate quickly from at least two sides, so reaching all the contents of the box at the same time. With shallow boxes and properly designed electric furnaces employing top and bottom heat only, these conditions are satisfied. Figs. 1 and 2 show typical box type furnaces employed for the carburising of steel parts, using solid carburising agents. Care should be taken that if more than one piece is carburised in a box that there is at least ½ in.–1 in. layer of carburising compound between all faces, so that the surfaces may be evenly heated and carburised. When the work has to be cooled in the box it is important that the box is of such dimensions that very slow cooling, causing a network in the hypereutectoid case is avoided.

The packing of steels into carburising boxes requires attention, and the method of packing must of necessity vary with the type of article being handled ; for example, long slender pieces should be packed vertically so that no sag takes place under the influence of high temperatures. Compound is first placed in the bottom of the box to a depth of 1½ in.–2 in., and the parts then evenly spaced are placed firmly on this bed and covered with a layer of carburiser, so that if further layers of articles are placed in the box any article is remote from its immediate neighbours by at least ½ in.–1 in. of compound. After completing this operation, a final layer of some 2 in. of compound is placed at the top of the box and the lid then placed and luted into position. The box is now ready for heating up, and this should be gradual, at least up to 700° C., because at this temperature there is a strong liberation of gases. After 700° C. the heating should be uniform up to the desired carburising temperature, which may lie between 900°–1,000° C., although the most generally adopted range for standard carburising steels lies between 875°–925° C. Boxes may be heated in either continuous or batch type furnaces, the latter being in more common use in this country than are the former. If desired, the temperature of the box may be lowered towards the end of a run in order to allow for a diffusion period without further addition of carbon to the surface of the steel.

A carburised case after hardening is unmachinable, so that any parts which have to be machined or drilled after carburising must be kept soft and uncarburised, unless of course the work is cooled from the box and the machining done before quenching for hardening. The general methods employed for preventing carburisation are the use of clay-bonded coatings or copper-plating. It is essential with the latter process to obtain an even, sufficiently thick pore-free and adherent copper plate if the surface is to be adequately protected.

In determining the extent of the carbon penetration during carburisation of any particular steel, the two most important variables are temperature and time of treatment.

Regarding the former, it may be taken for granted that the most commonly employed carburising temperature is

900° C. The general effect of raising the temperature from 850° to 1,000° C. is to increase the amount of carbon absorbed by the steel; to alter the carbon gradient which is steeper the lower the temperature; and to alter the depth of penetration which increases in a linear manner with rise in temperature.

Concerning the effect of time on carburisation, it is known that when using any form of carburising medium at a given temperature, the first few thousandths of an inch of case are put on quite rapidly, after which the process slows up. Stated very simply, this means that if the period of carburisation increases in geometrical progression the depth of penetration of carbon also increases in this way, but with a different common ratio. The following table gives some information on the depth of penetration of carbon at various temperatures and various times of treatment :—

Method.	Temperature of Carburisation.	Time in Hours.	Approximate Depth of Penetration in Inches.
Ordinary solid carburising compound.	975° C.	1	0.045
		2	0.065
		4	0.090
		8	0.130
	850° C.	1	0.020
		2	0.033
		4	0.050
		8	0.065

There is one other variable—namely, the effect of the initial concentration of carbon in steel,—but for all practical purposes the depth of penetration is not affected by this initial concentration. Furthermore, the greater portion of steel carburised concerns low carbon steels and low alloy carbon steels.

Use of Liquid Carburisers—Salt Baths

In specific cases, particularly if the parts to be case-hardened are of very intricate design and a uniform case is essential, diffusion of carbon into the surface layers is carried out by means of salt baths. The composition of the bath varies but slightly these days, and generally consists of the mixed cyanides and carbonates of sodium and potassium. Some of the early salt baths for carburising contained sodium chloride, sodium ferricyanide, borax, and various grades of sugar. The baths may be heated to the desired carburising temperature either by electrical means or by the combustion of gas or oils. Such carburising baths find extensive application on parts where very slight wear ruins the object, such as automobile gears, and a thin, high carbon, wear-resistant case only is required. In such cases a surface skin which contains carbon and nitrogen is produced in a short period of carburisation. Solid carburisers do not in a short time readily produce a hypereutectoid case, so that for a thin hypereutectoid case resort may be made to cyaniding or properly controlled gas carburising. In general shop practice, the pieces to be carburised are either suspended on hooks or wires or placed in special alloy baskets. These are supported across the top of the furnace by suitable brackets. It is essential that all parts should be free from rust and moisture, this latter being overcome by preheating the parts prior to entry into the salt bath. Normally, work is carburised in modern cyanide baths at temperatures in the region of 950° C., where, however, due to the slender nature of the parts being treated, distortion is feared, slightly lower carburising temperatures are employed.

Use of Gases for Carburising

When discussing earlier in this article the oldest known methods of carburisation of low carbon steels by solid carburisers, it was made apparent that the diffusion of carbon, although a definite case of solid diffusion occurs only by the gas reactions taking place at the surface of the steel, whereby atomic carbon is made available which can diffuse into the steel. It is thus a very logical conclusion to assume that if the same gas or gases are brought into contact with heated iron and steel, carburisation should occur without the necessity for the presence of solids. This actually is the case, but whilst the active carburising gas liberated by solid carburisers is carbon monoxide, it is not altogether a feasible commercial proposition to carburise by means of pure CO. Furthermore, it is not possible to obtain uniform and consistent results by the use of any of the gases made available in the larger metallurgical industrial operations, such as producer gas, town's gas, etc., which contain CO. Commercial carburising by the use of gases has found little application in this country, but in the United States, where large quantities of natural gases are available, considerable progress has been made.

A number of points will be apparent when comparing gas carburising with other methods using solid and liquid carburisers, such as absence of storage space and labour in handling the carburising compounds, no mixing with spent material, no "topping-up" of the bath, and most important of all, production is speeded up because of the decrease in heating time, as no insulation effects characterising the other processes are experienced. On the other hand, extreme care and attention must be paid to the physical chemistry of the gas used, and such points as control of humidity, constancy of gas composition, rate of flow of gas watched carefully. Hydrocarbons provide the most suitable atmospheres for gas carburising, and whilst the production of a case and the diffusion of the carbon proceeds along analogous lines to the other methods of carburising, the reactions occurring at the surface of the steel are different. Another point to bear in mind is that if considerable sooting occurs then this does not enhance but prevents carburisation.

In the States, various types of electric furnaces have been employed for gas carburising, including semi-continuous, tumbling and circulated gas types, each type being used for specific requirements.

Conclusions

It has not been possible in this article to deal at any length with many of the theoretical problems in connection with carburisation, with particular reference to the use of solid media, but sufficient has been given to indicate that pure research work carried out on the subject of carbon diffusion has led to important applications in the industrial field.

Northern Aluminium Research Department

The research Department of the Northern Aluminium Co., Ltd., has now been amalgamated with that company's sales engineering and development department. The new department will be known as the Research and Development Department, and Mr. Gordon H. Field, who this year completes 25 years' association with the aluminium industry, will be research and development manag r, and Mr. F. R. C. Smith assistant manager. In addition to und rtaking research and development work in connection with the company's products, the new department will be available to give advice in respect of customers' problems in connection with the use or possible use of aluminium and its alloys. The research and development department will be stationed at Banbury.

Errata

In the article entitled "A Metallurgical Survey of Machine Cutting Tools" by Mr. H. W. Pinder, published in our March issue, the phosphorus contents of the typical steels for roughing and finishing tools, given in the table at the top of page 161, should read 0·020, 0·021, and 0·020. Immediately under the illustration on the same page the first line of type should read, "advisable to re-anneal by heating slowly to 650° C.," etc.

A Comparison of Single Heat-treatment and Double Heat-treatment Aluminium Alloys

By Oswald R. Smith, B.Sc.

(Research and Development Department, Northern Aluminium Company, Ltd., Banbury.)

In this article attention is given to a comparison of the general characteristics of single heat-treatment aluminium alloys and double heat-treatment aluminium alloys, the effect of the heat-treatments involved, the properties, ease of forming and manipulation.

WROUGHT aluminium alloys are mainly of two classes, either strain-hardened or heat-treated. The majority of the wrought light alloys for high service conditions are of the heat-treated type, which may be sub-divided into two main groups—(1) those which are given a solution heat-treatment and subsequently "age-harden" at room temperature in from four to five days; and (2) those which, after solution heat-treatment, require to be given an additional treatment for the requisite period at approximately 150° to 180° C. in order that maximum properties may be obtained.

Both the single and double heat-treatment class of alloys have their place among the leading aluminium alloys used in the aircraft industry, in road and sea transport, and in fact wherever lightness is called for in an easily manipulated material required to undergo severe service conditions.

In the single heat-treatment class of alloys, in which duralumin is by far the most widely used material, the solution heat-treatment is usually carried out either in a nitrate salt-bath or in an electrically heated air furnace. The heat-treatment temperature ranges from approximately 480° C. to 505° C., according to the particular alloy. After quenching in water, the material ages naturally at room temperature. The alloying constituents which go into solution in the alloy during the solution heat-treatment operation produce a super-saturated condition in the material on quenching, of such a nature that the constituents start to precipitate in a sub-microscopic form and continue to do so for about five days, until a stable condition is reached.

Fink and Smith[1] state that their work on the age-hardening of aluminium alloys "led to conclusions, consistent with the precipitation theory originally proposed by Merica, Waltenberg and Scott, that age-hardening results from the controlled decomposition of a super-saturated solid solution accomplished by the formation of nuclei of a second phase." "The particles precipitate preferentially in regions that have been plastically deformed during quenching in cold water—that is, along the grain boundaries and the slip bands." "Growth of the precipitated particles occurs by the usual process of crystal growth, and the changes in physical and mechanical properties are explained in terms of this normal precipitation process."

The precipitation may be accelerated by raising the temperature of the material, for example, by maintaining it for 2 hours at 170° C., but natural ageing is generally recommended.

The double heat-treatment class of alloys receive exactly the same solution heat-treatment and quenching operation as the single heat-treatment alloys.

In the case of double heat-treatment alloys, however, solution of the alloying constituents during heat-treatment is not effected so rapidly as in single heat-treatment alloys, probably due to the increased added elements usually present in these alloys, such as iron and magnesium. The super-saturated condition on quenching the material is usually such that precipitation at ordinary room temperature is extremely slow.

Precipitation of the hardening constituents in double heat-treatment alloys is considerably affected by the temperature at which the quenched material is maintained, just as in the case of single heat-treatment alloys, increasing temperature aiding the rate of precipitation.

The precipitation is generally artificially accelerated by heating the quenched material for a number of hours, usually at 150° to 180° C. for 10 to 20 hours. The time and temperature depend on the particular alloy and size and weight of load, adjusted according to the size of furnace, in order to ensure that the material at the end of this artificial ageing treatment is in the fully aged and stable condition.

Over-ageing the material by using too high a temperature or too long a period of time has similar detrimental effects to forcing the rate of ageing of the single heat-treatment class of alloys.

Alloys of the single heat-treatment class include sheet of duralumin type to British Standard Specification 5 L. 3 and Alclad sheet of super-duralumin type to Air Ministry Aircraft Materials Specification D.T.D. 390. Extruded sections and forgings up to 3 in. cross section in this class of alloy are required to meet B.S.S. 6 L. 1, and over 3 in. to meet B.S.S. 2 L. 39. Duralumin tubes are covered by B.S.S. 4 T. 4. The solution heat-treatment temperature of these materials is 495° C. ± 10° C., and an important characteristic is the effect of overheating the material. The B.S. Specifications clearly emphasise that on no account in workshop practice should the temperature be greater than 505° C., owing to the danger of overheating the material and rendering it brittle in consequence. Duralumin forged airscrew blades to either D.T.D. 147 or D.T.D. 150, and "Y" alloy forgings, pistons and cylinder heads to B.S.S. 4 L. 25 are included in the single heat-treatment class. Of the casting alloys amenable to heat-treatment, the majority are "aged" artificially, but one alloy which ages naturally is that covered by D.T.D. 250. These materials, which have been used in large quantities in aircraft production in recent years, have a high strength-weight ratio when their natural ageing is completed'

Wrought alloys of the double heat-treatment class include super-duralumin type alloy sheets to D.T.D. 356, and aluminium coated sheets to B.S.S. L. 47. Extruded sections and forgings are covered by B.S.S. 2 L. 40, L. 45, and D.T.D. 364. Drop forgings, pistons and cylinder heads are covered by B.S.S. 2 L. 42. All these alloys have a maximum solution heat-treatment temperature of 535° C., which, if exceeded, will usually lead to inferior quality material in one property or another, such as a lower fatigue value. Their artificial ageing treatment is carried out at approximately 165° ± 10° C. Material to D.T.D. 363 is heat-treated at 460° C. and aged at 130° C.

Heat-treatable casting alloys are nearly all of the double heat-treatment class. These include "Y" alloy, RR 53 and 53 C, Ceralumin "C," "Lo-Ex" and NA. 226. Their solution heat-treatment temperature ranges from 500°–540° C., and the ageing temperature 150° to 180° C.

Comparing the characteristics of the single and the double heat-treatment classes of alloys, the single heat-treatment type wrought alloys in the finally aged condition have a definite advantage in ductility, impact strength,

1 W. L. Fink and D. W. Smith: "Age-hardening of Aluminium Alloys." *Metals Technology*, A.I.M.E., June, 1939.

COMPARISON OF MECHANICAL PROPERTIES OF SOME HEAT-TREATED ALUMINIUM ALLOYS.

Single Heat Treatment Alloys.				Double Heat Treatment Alloys.			
Specification.	0.1% Proof Stress. Tons/sq. in.	Ultimate Tensile Stress. Tons/sq. in.	Elongation % on 2 in.	Specification.	0.1% Proof Stress. Tons/sq. in.	Ultimate Tensile Stress. Tons/sq. in.	Elongation % on 2 in.
Bars, Billets, Extruded Sections, Forgings.							
B.S.S. 6.L.1	15	25	15	B.S.S. 2.L.40	21	27	10
				D.T.D. 363	27	33	8
				D.T.D. 364	26	30	8
				D.T.D. 423	17	22	8
Sheets and Coils (uncoated and aluminium coated).							
B.S.S. 5.L.3—Over 12 in. wide	(T) 14.5	25	15	B.S.S. L.47	19	25	8
12 in. and under	(L) 15	25	15				
B.S.S. 2.L.38	13.5	24	15				
D.T.D. 390	15	25	15				
Tubes.							
B.S.S. 4.T.4	18	26	8, 10 and 12.5	D.T.D. 220A	(0.2%) 23	27	6, 8 and 10

and corrosion resistance. Their chief disadvantage lies in the shortness of time in which forming operations can be performed after solution heat-treatment before the progress of natural ageing prevents further work being carried out.

The chief characteristic of the double heat-treatment wrought alloys is their comparatively stable condition after solution heat-treatment, in which state they are quite ductile and considerable forming operations can be performed, followed later by the artificial ageing process. Thus, when aircraft constructors desire to carry out severe forming operations, instead of using single heat-treatment alloys which would require re-solution heat-treatment before forming, they have the alternative of using double heat-treatment alloys supplied in the solution heat-treated condition ready for forming. After forming, the alloys are given the low temperature precipitation treatment specified for the particular alloy. The time latitude already mentioned is one of their main workshop advantages, in that the forming operations need not be carried out immediately after solution heat-treatment and quenching.

After the ageing treatment, the double heat-treatment alloys have the advantage of greater strength by some increase in the tensile strength, but particularly in higher proof stress than in single heat-treatment alloys. The minimum proof stress allowed for single heat-treatment materials ranges from 13½ to 15 tons per sq. in., with a good elongation, the minimum being usually about 15%. The minimum proof stress of double heat-treatment alloy sheet to B.S.S. L. 47 is, however, 19 tons per sq. in., and 21 tons per sq. in. for extruded sections to B.S.S. 2 L. 40. These higher properties in tension are attained at some expense of other properties, such as impact strength and ductility, together with rather less corrosion resistance than the single heat-treatment alloys possess.

The modulus of elasticity values for both single and double heat-treatment alloys are slightly higher than that of commercially pure aluminium, and are in general closely similar for both classes of alloys.

Regarding fatigue properties, a certain variation of endurance ratio—that is ratio of endurance limit to ultimate tensile strength, is obtained for both single and double heat-treatment alloys, and there is no conclusive evidence that the average value is substantially different for the two classes.

Considering resistance to corrosion, the single heat-treatment type are, in general, superior. Whilst the heat-treated alloys containing copper are not as resistent as those containing magnesium, but free from copper, the question of corrosion resistance, and particularly resistance to intercrystalline attack of components under static stress, is to a great extent for any individual alloy dependent on the details of the heat-treatment technique.

Grogan and Pleasance,[2] after examining "Y" alloy and 4% copper-aluminium alloy, found that "material rapidly cooled from the solution treatment temperature by quenching in cold water is free from intercrystalline attack when submitted to sea-water spray, and that in this case corrosion is not influenced by the imposition of static tensional stress on the material during exposure. Material more slowly cooled—e.g., in air—is susceptible to intercrystalline corrosion, which is markedly stimulated by the imposition of static stress." Their investigation showed that quenching in cold water results in less likelihood of intercrystalline corrosion than quenching in hot or boiling water. This confirms the work of previous investigators.

In the case of thin materials with a large surface area to cool rapidly, such as thin sheet, the time in seconds from furnace to quench is important. Zeerleder[3] has stated that in order to avoid any tendency to intercrystalline corrosion in duralumin sheets, the pre-cooling time from furnace to quench should be less than 15 seconds.

Whereas in the single heat-treatment alloys the corrosion resistance is not affected by the natural ageing at room temperature, and is chiefly dependent on chemical composition and details of the solution heat-treatment, the corrosion resistance of double heat-treatment alloys, while still being dependent on chemical composition, is adversely affected by the artificial ageing treatment at elevated temperatures.

Another factor adversely affecting corrosion resistance is the tendency, in aiming for increasingly higher tensile properties, to overload the age-hardening alloys with excessive quantities of additional elements. In this respect the single heat-treatment alloys have the advantage.

It will be gathered from the foregoing that in many respects the single heat-treatment alloys hold their own against the newer and stronger artificially aged alloys. As already mentioned, their chief disadvantage has been the shortness of time in which severe forming operations may be carried out after solution heat-treatment. A particular instance of this, especially in aircraft construction, is in the use of duralumin rivets to B.S.S. 2 L. 37. The specification itself points out that rivets commence to harden immediately they are stored at atmospheric temperature following quenching. If the rivets age to such an extent that they become too hard for closing, they require reheat-treatment before use. Ageing may be delayed by storing the rivets at low temperature immediately following quenching, the period of delay depending on the storage temperature—at atmospheric temperature for 2 hours; at 0° C. to −5° C. for 45 hours; and at −15° to −20° C. for 150 hours. Naturally, after storing rivets at low temperature, they

2 J. D. Grogan and R. J. Pleasance, *J. Inst. Met.* 1939. 64, p. 57.
3 Zeerleder, *J. Inst. Met.* 1939 64 p. 76.

require to be "closed" within 2 hours of removal from cold storage, since age-hardening proceeds at atmospheric temperature.

The use of refrigeration for delaying the age-hardening of duralumin type alloys, with special reference to the production of large pressings for aircraft, has recently been fully developed as an industrial process and described by Arrowsmith and Wolfe.[4] A description of suitable equipment has also appeared in the technical Press.[5] By such refrigeration means the chief disadvantage in the pressing and forming of the single heat-treatment alloys may be overcome.

Where comparatively little or no forming is to be done, the use of a single heat-treatment alloy obviates the trouble and cost of a separate ageing treatment. The tensile properties, particularly the proof stress, may not be quite so high, but the resistance to corrosion will generally be greater with approximately equivalent fatigue value and higher impact value when compared with a double heat-treatment alloy.

The foregoing comparison of the two types of heat-treated alloys has shown that by double heat-treatment certain advantages can be gained, but only at some expense of other valuable properties. In the selection of a single or a double heat-treatment alloy for any particular purpose, therefore, it is necessary to give full consideration to all the conditions required of the material in service, in addition to its suitability from the manufacturing and fabrication point of view. Particularly it is desirable to avoid placing too much value on the tensile properties alone, which may have been obtained at the expense of other equally valuable properties.

4 J. C. Arrowsmith and K. J. B. Wolfe. Paper submitted to Inst. Met., Nov., 1939. Ref. synopsis. *J. Inst. Met.*, March, 1940.

5 "New Refrigeration Storage System for Age-hardening Aluminium Alloys." *Light Metals*, III, 26, March, 1940, p. 67.

A General Outline on the Heat Treatment of High-Speed Steel

By H. W. Pinder

The quality of high-speed steel tools and their ability to function efficiently in practice are dependent upon the suitable correlation of chemical composition, hot working, and heat-treatment. The latter operation is highly complicated, largely due to the infinite number of intricately designed tools in service, and this general outline, which embraces all operations involved in the heating and cooling cycle for the heat-treatment of high-speed steel, will have a practical value.

THE importance of producing highly efficient heat-treated high-speed steel tools is of the greatest moment to engineers and machinists, especially under prevailing conditions, and during recent times this subject has received the increasing attention of both the metallurgist and the furnace engineer. For the purpose of this article, therefore, the term heat-treatment is taken to embrace all operations involving a heating and cooling cycle devoid of mechanical work, but designed to produce a definite micro-structure or hardness within the steel.

Annealing

Dealing with the heat-treatment operations in the order in which they occur in practice, the annealing of high-speed steel ingots is discussed first. Such an operation is considered necessary only should it prove impracticable to strip the ingots hot—i.e., at a minimum temperature of 700° C., and charge immediately into a furnace standing at a similar temperature for heating to the forging temperature. If this procedure is not followed, the ingots should be stripped warm and finally cooled very slowly. The ingots can then be heated for forging, during which operation every care must be taken, as they are in a fragile condition; alternatively, they can be subjected to a preliminary anneal.

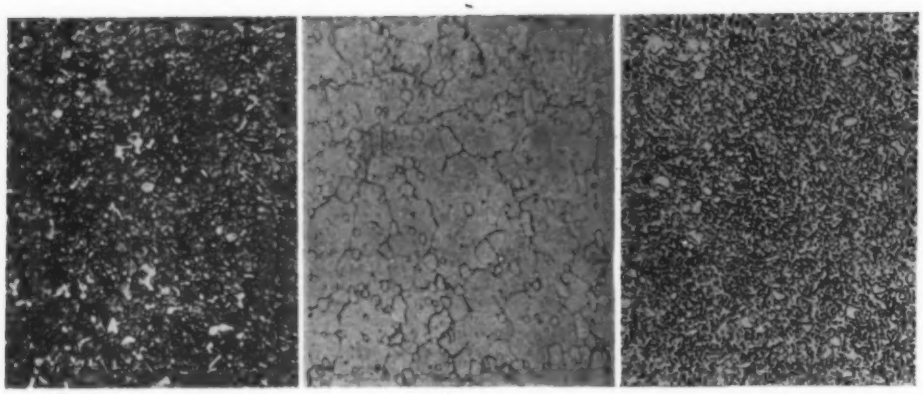
When an annealing treatment is decided upon, the ingots should be placed in a cool furnace and heated steadily to a temperature of 880° C. to 900° C. in 12 to 15 hours, according to the size of ingot; soaked for 8 to 10 hours; then cooled slowly to 650° C. at the rate of 20° C. per hour, following which the cooling rate can be speeded up considerably, as no further thermal changes occur. After such a treatment the ingots are soft and free from internal stress, hence they can be heated for cogging more rapidly without risk of cracking.

The second heat-treatment given to high-speed steel usually follows the final hot working of bar or blank. Again, the treatment is one of full annealing, but in this case the object is the production of a definite structure representing the steel fully softened, so that the material will respond readily to machining and subsequent heat-treatment. The annealing treatment given in this case is almost identical to that described for ingots except that at this stage the material is packed into tubes or boxes in order to minimise the loss of carbon. Following such an annealing treatment the Brinell hardness should be reduced to a maximum figure of 248.

After machining certain types of large tools on which comparatively heavy machining cuts have been taken, failure to carry out a subsequent stabilising treatment might lead to serious distortion or even cracking. Such a treatment consists of placing the tools in a cold furnace and raising them steadily to a temperature of 650° C. over a period of 8 to 10 hours, holding for an hour, and cooling at a similar rate to that of heating. After the temperature has fallen to 200° C., however, it is satisfactory to withdraw the tools from the furnace and cool in still air.

Hardening High-speed Steel

The hardening of high-speed steel is a somewhat complex operation, the initial object of which is to retain in solution by cooling from a high temperature the maximum amount of carbide, but avoiding a coarse, grossly overheated structure. The reason for the employment of very high hardening temperatures is explained by the fact that the composition of the austenite is such that the complex carbide is only taken into solution at a comparatively slow rate, even at temperatures above those usually employed for normal hardening operations, thus in order to overcome this sluggishness the use of very high temperatures is essential. Additionally, it is not possible to take all the carbide into solution and produce a structure of satisfactory grain size, but the less carbide taken into solution the more plentiful are the nuclei which persist for a re-deposition during quenching, and below a certain hardening temperature for a given steel this fact will reveal itself by a low hardness should the tool be fully tempered. The hardening range for high-speed steels varies between 1,200° C. and 1,360° C., depending on the composition o the steel.



FORGED AND ANNEALED. QUENCHED. QUENCHED AND TEMPERED.

Fig. 1.— Photomicrographs showing typical structures of high-speed steel in various conditions. x 500

Table I gives typical analyses, and hardening and tempering temperatures for such steels. After hardening, it is essential to temper in order to produce a relatively stable martensitic structure of intense hardness. As in the hardening operation, the secondary hardening treatment will vary according to the composition of the steel.

Having given a broad theoretical outline of the heat-treatment of high-speed steel, it will be considered now from a more practical standpoint. Table I serves as a general guide to the temperatures employed in hardening and tempering according to the type of steel being treated. Obviously, however, such a practical discussion of the subject can be surveyed only generally, as the many different types of tool require particular care and attention. Nevertheless, an attempt will be made to indicate some of the necessary precautions essential to the successful heat-treatment of high-speed steel tools.

Assuming the tools for hardening have a well-annealed structure, and that they are relatively free from machining stresses, they should be warmed by putting them in a convenient place in the shop, such as a furnace top or hot plate, and then transferred to the preheating chamber. It is usual for this furnace to be standing between the temperatures of 850°–880° C. In the case of very complex tools which contain large differences in section, such as large milling cutters, it is often advisable to institute an intermediate preheating operation in the temperature ranges 550°–600° C., and 1,050°–1,100° C., so as to reduce, firstly, the risk of too sudden heat changes, and, secondly, overheating the edges of the teeth before the thicker sections are nearing the hardening temperature. It will be realized therefore that adequate preheating is absolutely essential if the temperature gradient between the large and small sections, and the outer and inner portions of the tool is to be reduced to a minimum by the time the full hardening temperature has been attained. At each preheating temperature the steel should be heated through, the time for which will depend on the section of the tools.

Following a thorough preheat, the tools should be transferred to the high-temperature chamber for hardening. If the optimum results are desired from a hardened tool, it is essential that both the preheating and the hardening chambers should be atmosphere controlled. Should the preheating chamber have an uncontrolled atmosphere and the hardening chamber a controlled atmosphere, the conditions in the latter will have to be modified, compared with those which would obtain if used in conjunction with an atmosphere controlled preheating chamber. This is at once apparent when it is realised that in the one instance a tool having a scaled surface would be introduced into the high-temperature chamber for hardening, and in the other instance the tool would be almost free from scale. It is therefore better that both the preheating chamber and the hardening chamber should be atmosphere controlled.

The conditions desirable in the hardening chamber are those which allow the maximum carbide solubility without the production of a grossly overheated structure, the preservation of the fine contours of the tool, and a minimum loss of carbon from the exposed surfaces. It should be noted, however, that for many applications a grain size which has a tendency to be coarse has not proved as detrimental in service as one might have supposed, and, providing there is no incipient fusion or intergranular oxidation, such tools have very often behaved exceedingly well during service, so long as they were not called upon to withstand abnormal shock.

By the institution of atmosphere controlled furnaces, and this includes the use of salt baths, a liberal expansion of the control required for consistent hardening has been acquired. For example, it is claimed for one design of gas-fired furnace that results obtainable with any class of steel requiring to be heated at any temperature up to 1,385° C. are consistent, and it can be guaranteed that there is no decarburisation, and not more than 1/10,000 of an inch of scale formed on the surface of the steel. Furthermore, these claims have been substantiated in a number of works producing form tools, where grinding after heat-treatment is not permissible. Therefore, by the use of controlled

TABLE I.

—	C.	Mn.	Si.	W.	Cr.	V.	Mo.	Co.	Heat-treatment.
14% tungsten type...	0·71	0·35	Max. 0·3	Max. 14·0	4·0	0·98	—	—	Hardening temperature, 1,300° C. Tempering temperature, 560°–580° C.
Tungsten 18/4/1 type	0·78	0·35	0·3	18·5	4·5	1·3	—	—	Hardening temperature, 1,320° C. Tempering temperature, 580°–590° C.
Tungsten cobalt type 1.	0·79	0·35	0·3	19·2	4·4	1·5	—	5·0	Hardening temperature, 1,340° C. Tempering temperature, 580°–590° C. twice.
Tungsten cobalt type 2.	0·82	0·35	0·3	20·1	4·5	1·6	—	18·0	Hardening temperature, 1,360° C. Tempering temperature, 580°–590° C. three times.
Molybdenum tungsten type.	0·75	0·35	0·3	2·5	4·2	1·0	8·5	—	Hardening temperature, 1,200° C. Tempering temperature, 560° C.

atmosphere furnaces for hardening the final grinding operations can be entirely eliminated. It should not be imagined, however, that one atmosphere is satisfactory for all temperatures or all compositions. On the contrary, each composition and temperature has an optimum gas atmosphere composition.

It is interesting to note how the composition of the gas varies with the composition of the steel and the hardening temperature. Consider two samples of 18% tungsten steel, one of which would normally be hardened at 1,300° C. and the other, because of small additions of cobalt or molybdenum, at 1,330° C. If the controlled atmosphere is properly adjusted to give the correct surface results on the steel hardened at 1,300° C., the fact of increasing the temperature to 1,330° C. would materially alter the composition of the purging atmosphere. The result would be to produce a greater percentage of reducing gases, so when working at 1,330° C. it would be advisable to adjust, by means of the control on the furnace, the composition of the purging gases. The change to be made would thus entail a reduction in the percentage of reducing gases. In the case of steels containing 5% cobalt or higher, necessitating the use of even higher temperatures than 1,330° C., this feature becomes even more pronounced, and consequently further adjustment is necessary to keep down the percentage of reducing gases if freedom from decarburisation is to be assured.

Having therefore discussed briefly the conditions which exist in the hardening chamber of a high-speed steel furnace, the next consideration is the period during which the tool should be held at the high temperature. This will be governed by the shape and section of the tool. For example, it would not be possible to allow the larger sections containing sharp teeth to attain to the temperature of the furnace, since it would result in oversoaking the edges of the teeth, but this could be more nearly accomplished in atmosphere controlled furnaces, where longer times at the hardening temperature are permissible with less risk of overheating. Times for which tools are held in the high-temperature chamber, therefore, will vary from a few seconds to several minutes, according to shape, section, and the preheating temperature to which the tool was heated. The best way of determining this period is accomplished by trials with suitably selected spy pieces. Following the high-temperature treatment, quenching is conveniently carried out in oil, an air blast, or still air.

When the tools are of uniform section, such as tool bits, there is no reason why they should not be quenched right out in oil, as this preserves the surface of the tools and prevents decarburisation during their cooling through the high-temperature range. However, if the tools are fairly long and complex they should be cooled in oil for five to seven seconds, followed by a vigorous air blast. Where tools are long and slender they can be suspended in a blast, which delivers air uniformly to all parts. By this method distortion can be almost entirely eliminated. Whatever method is used for quenching, the tools should be removed from the quenching media as soon as they can be handled—i.e., when hand warm. Tools of intricate section should then be placed in a tempering bath preferably at a low heat of 200°–250° C., although for small tools of uniform section they can be placed in a furnace at a higher temperature—say, 350° to 400° C. Failure to temper immediately or observe these precautions will increase the risk of cracking. After allowing time for equalisation, they should be raised steadily to 580°–590° C., held for a period according to section, and finally cooled in air.

The number of temperings to which the tools are subjected is important. The normal tempering treatment which straight 18% tungsten high-speed steels are given consists of one complete cycle—i.e., one heating and cooling. For 5% and 10% cobalt steels the tools are usually tempered twice, and in the case of 18% cobalt high-speed steel tools as many as three temperings are given. Recently the tendency has been to heat the tools to lower tempering temperatures, but repeat the cycle more often. This method has been tried as the result of some observations reported in a letter to *Metal Progress* in May, 1936, and confirmed subsequently by work in Britain and America. These investigations suggested that the breakdown of retained austenite occurred chiefly during heating and cooling rather than at the tempering temperature, and that by heating to a temperature as low as 540° C., and repeating two or three times a greater hardness was developed in an 18% tungsten steel than was normally the case. Cobalt high-speed steels would require even more temperings. Whether the extended tempering treatments were justified by the slight increase in hardness, however, does not appear to have been confirmed in practice as yet.

Hard Surfacing

INCREASED interest has been taken in hard surfacing during recent years, due to an appreciation of the value of developments of this process in resisting wear, corrosion or both. Many processes are now used in applying metals to surfaces with the object of reducing the wear of a working part so that by prolonging the life of that particular part the machine in which it operates can function for a longer period without replacement of the part and subsequent loss by idle machine time during replacement. Generally, the advantages of hard facing are: increased life, low co-efficient of friction, resistance to corrosion, permits the use of a cheaper or more easily formed base metal, and lower cost.

Hard surfacing should not be confused with surface hardening, in which the parent metal is subjected to treatment, and it is necessary to decide, in any particular case, either to have material different from the parent metal or to process the parent metal so that the surface will provide the resistance desired. All parent metals, even all steels, cannot be carburised, nitrided or otherwise surface hardened, but a ferrous metal and non-ferrous metals may be successfully hard-faced, chromium plated or metallised. Hard facing depends on a welded bond; chromium plating upon an electrolytic bond, and metallising on a mechanical bond. As pointed out by Prof. M. L. Begeman* each process has certain limitations, and a determination of what is best to do necessitates taking into account these limitations as well as the benefits they may possess.

It is believed that the development of hard-facing materials was first adopted in cement plants as a means of protecting equipment, while oil-well drilling companies have been using hard-faced rotary drills for nearly 20 years. As a result of developments in suitable materials and in application, many other industries used the process as a solution to a number of problems. One example has been the adoption of a cobalt-chromium-tungsten hard-facing alloy for valve seats for steam and internal combustion engines. No one hard-facing material is completely satisfactory for every application. Tungsten carbide may be the most suitable for use where friction is the deciding factor, provided little or no impact is encountered. For smooth bearing surfaces or corrosion resistance, the cobalt-base non-ferrous alloys are best. An austenitic alloy is used to withstand great shock.

There are essentially five groups of hard-facing materials. These are, in the order of increasing wear resistance:—Alloy steels containing up to approximately 20% of alloying constituents; iron-base alloys containing over 20% of alloying constituents; non-ferrous cobalt-chromium-tungsten alloys; crushed tungsten carbide diamond substitutes, which, after welding, are embedded in a steel binder, and cast tungsten carbide inserts. The order of their toughness is approximately the opposite of wear resistance. The most significant development in these alloys has been the increase in toughness of the harder classes of materials. Many manufacturers now apply these hard-facing materials to new parts before they are marketed.

* Contribution to the Literature Division, Welding Research Committee, A.S.T.M.

Some Recent Heat Treatment Furnace Installations

Although no strictly new heat-treatment processes have been developed in recent years, experience with existing methods has been productive of improved procedures. Furnace plant has been made more accurate and capable of producing conditions which greatly assist in meeting the requirements for more exacting properties from materials treated. It is only possible to review briefly some of the more recent furnace installations.

TOO much emphasis cannot be placed on the importance of metallurgical control of all heat-treatment operations in order to develop in the materials treated the properties desired. Specification requirements have become so exacting in recent years that close control of every process is essential to success in meeting these requirements consistently. It is necessary not only to control the temperature and the rate at which heat is absorbed by the material undergoing heat-treatment, but also the conditions under which the material is heated and the rate of cooling.

Heat-treatment furnaces to-day are so greatly improved that they may be regarded as precision tools which will give efficient service, providing they are adequately controlled for that service. There is a wide variety of types, some of which are designed for general purposes within a particular range of temperature, others are designed for special purposes, and their range of usefulness is within narrower limits. There is also considerable variation in the treating medium, but furnaces, whether heated by solid, liquid or gaseous fuels, or electricity, including the equipment associated with them, should be selected for the useful service they can render when properly applied to individual requirements, and consideration should be given to the economic value of the operations performed in them, which is properly measured by the quality and total cost of the ultimate product or its life in service.

The work may be heated in a muffle furnace, in which it is protected from the heating flame and the products of combustion, or the gases may be allowed to enter the heating chamber. The furnace may be heated by electricity and an atmosphere of hot air which may be circulated in the heating chamber. In many instances the atmosphere in the heating chamber is of vital importance, and this is controlled either to protect the work against scaling or to produce a desired finish on the product. In addition to the more direct means of applying heat, various types of molten baths may be used to raise the work to a required temperature. Thus it can be treated in molten salts, in cyanide and in lead. Heating work in molten baths excludes any air from its surface during the time of heating, and the transfer of heat from the bath to the work is very rapid. In reviewing the developments of heat-treatment furnaces during the past twelve months, it is obvious that the demand for continuous equipment has been steadily increasing, and, as might be expected from increased production of these furnaces, their evolution has been greatly accelerated.

Continuous equipment is made for a wide range of treatments, including hardening, annealing, normalising, tempering and brazing, to mention just a few, and many different types are employed, such as pushers, walking beams, mesh belts, pan conveyers, rotary drums, continuous strip, rotary hearths, and a large number designed to suit individual treatments. It will be impossible to describe at great length all the types which come within the scope of this survey, so it is intended to refer only to more recent installations.

An equipment for heating non-ferrous rings has been particularly prominent lately, and various equipment has been manufactured to deal with a great variety of sizes. The furnace is of the pusher type, and an idea of its general construction can be gained from Fig. 1. The furnace is entirely self-contained, and occupies the minimum of floor space, all control gear and conveyer driving mechanism being mounted upon its structure. A high degree of efficiency is ensured, as it can quite easily be controlled by only one operator. To further this point, a vertical magazine is provided accommodating a minimum of 20 rings, so that continuous attention to charging is rendered unnecessary. This is of particular importance when the numerical output of rings is relatively high—that is, in the region of 250 per hour. The furnace is of muffle type construction and has a semi-circular heat-resisting liner along which the rings stand on edge. Automatic temperature control is included, and input reduction effected by the use of a variable pattern resistance.

The driving mechanism consists of a main pusher head mounted on a sliding shaft operated by a cam and rocker arm with spring return motion. The rings are conveyed from the magazine by an auxiliary pusher which brings them into the correct charging position in front of the main pusher. This auxiliary pusher is timed so that it operates during the rest period of the main pusher.

The rings, after travelling the length of the furnace chamber, are discharged automatically at the exit end down a curved chute, and here are removed by the furnace operator. The chute has a counterbalanced door which opens due to the weight of the discharged ring, and has

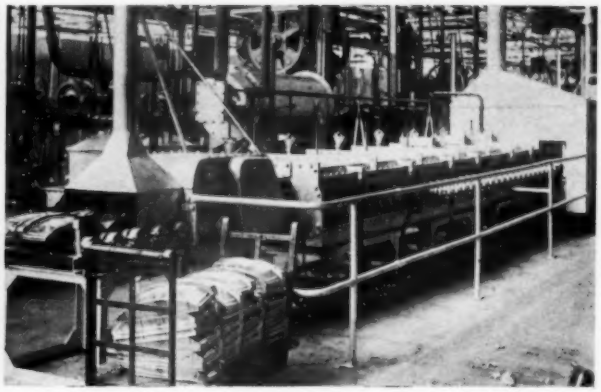
Fig. 1.—Continuous furnace of the pusher type for the treatment of non-ferrous rings. (Left)

Courtesy of Wild-Barfield Electric Furnaces, Ltd.

Fig. 2.—Continuous unit for hardening and tempering; it is used for bright treatments. (Right)

Courtesy of Incandescent Heat Co., Ltd.

Fig. 3.—Continuous bright annealing furnace heated by the "Multi Radiant" system.



Courtesy of Incandescent Heat Co., Ltd.

Fig. 4.—A bright annealing unit for treating radiator pressings.

also an entry for the admission of a protective atmosphere usually raw town's gas or steam.

Another furnace of interest is shown in Fig. 2, this is used for bright treatments, and is a hardening and tempering unit. This furnace is also of the pusher type, the components to be treated lending themselves to this method of travel. In the furnace shown the parts travel through the furnace in four parallel tubes, the motion being given by four synchronised pusher heads with common drive. The heating chamber is divided into sections or zones, and the temperatures are controlled by an automatic regulator covering each zone. The introduction of tubes to carry the work obviates the necessity of providing a gas-tight furnace casing and overcomes the difficulty of thoroughly purging the furnace chamber. A feature of particular interest is the small transverse charging conveyer at the entry end, on which the parts are loaded. This conveyer, when operated by the same driving mechanism which controls the main pusher, brings the parts automatically into the correct furnace-charging position.

A furnace installed recently for continuous bright annealing is shown in Fig. 3. Heating is effected by the patent incandescent "Multi-Radiant" system of the combustion of gas inside heat-resisting tubes; the sole function of these tubes is to generate and radiate heat, and since the products of combustion do not contact with the load, it is unnecessary to operate with a reducing atmosphere for protection. The conveyer system is of the roller hearth type, and consists of a series of compression rollers, closely spaced comprising a number of cylindrical refractory blocks, precision machine ground, requiring no water or air cooling, and therefore eliminating any heat losses due to the conveyer system proper. The conveyer has a useful temperature application up to 1,200° C., under conditions of light or heavy loading, and there is no pick-up, marking or scratching of the metal under treatment. The furnace shown is a typical example of this type of unit; it has a total length of 110 ft., and is used for bright annealing both ferrous and non-ferrous materials.

Another example of this type of bright annealing unit for treating radiator pressings is shown in Fig. 4. The total length of this furnace is 48 ft. 8 in., and the interior of the chamber is 2 ft. wide. Working temperature range from 450° C. for brass up to 950° C. for steel. This type of bright heat-treatment equipment has been applied to a wide range of heating, heat-treatment, and bright processing operations, covering ferrous and non-ferrous metals in the form of pressings, strip, wire, sheets and tubes, etc., at all temperatures up to 1,100° C. The system has also been applied successfully to continuous bright hardening; low temperature tempering and blueing; annealing castings and pressings prior to vitreous enamelling; sheet and tinplate normalising and annealing; and many operations not strictly associated with heat-treatment.

A recently installed normalising furnace of the continuous type is one designed and built by Messrs. King, Taudevin and Gregson, Ltd. It has been designed to deal with 60 tons of steel bars per 24 hours, varying from $\frac{3}{4}$ in. to 4 in. diameter, and between 12 ft. and 20 ft. long. An interesting feature in the design is the overhead heating by means of producer gas. The hearth of this furnace is 30 ft. long and 22 ft. wide, with a height of 1 ft. 6 in. to the roof. The bars to be treated are placed in a charging rack from which they are fed into the furnace progressively by means of a conveyer, which carries fingers of heat-resisting steel at intervals of 9 in. to accommodate the largest diameter of bars and allow space for uniform heating.

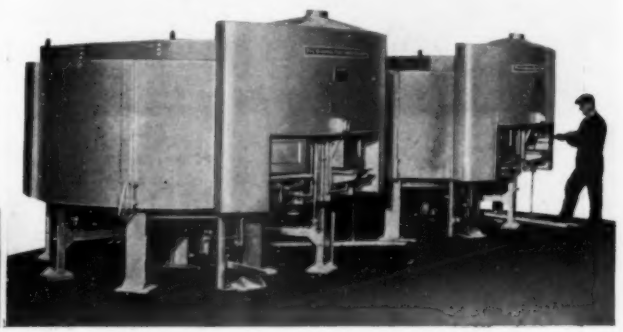
The speed of the bars through this furnace ranges between 1 ft. in 4 mins. to 1 ft. in 2 mins. The bars are heated for approximately half the distance travelled and subjected to a final heating period of a quarter of the distance, the

Fig. 5.—An unusual design of continuous furnace for normalising steel strip. (Left)

Courtesy of Siemens-Schuckert (Great Britain), Ltd.

Fig. 7.—Two rotary hearth furnaces for the general heat-treatment of steel parts for aero engines. (Right)

Courtesy of General Electric Co., Ltd.



Courtesy of G.W.B. Electric Furnaces, Ltd.

Fig. 6.—Rotary hearth furnace for hardening and tempering.

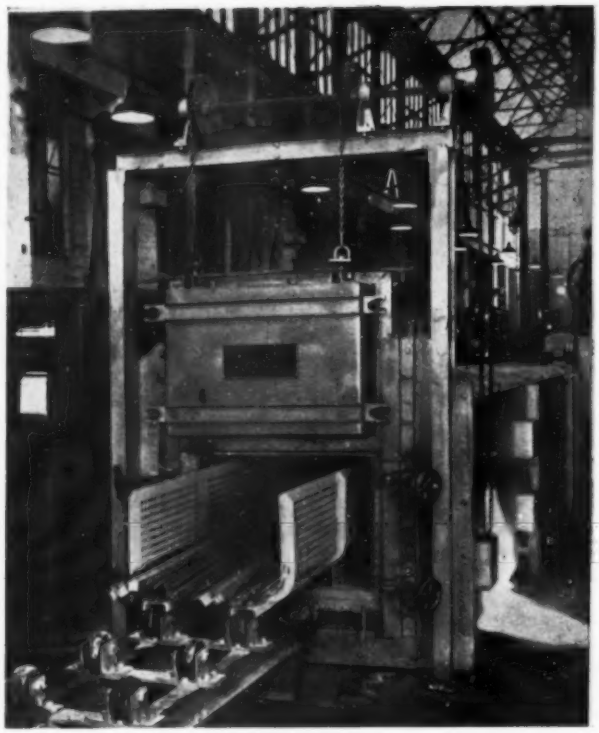
remaining quarter being arranged for cooling before discharging.

An unusual design of continuous furnace is that shown in Fig. 5. This is a heat-recovery tower furnace for hardening and normalising steel strip. Continuous steel strips are drawn up the tower through a heating zone at the top, over a roller and down the tower close to the rising portion of strip. The treated material thus transfers its heat to the incoming strip, resulting in recovery of nearly 50%. As a neutral atmosphere is used and the strip emerges cool, the steel retains its bright surface.

Several rotary hearth heat-treatment furnaces have been installed recently, and a typical furnace of this type suitable for annealing, hardening and tempering is shown in Fig. 6. This type of furnace is particularly suitable for the heat-treatment of small castings, gears, dies, etc., and only one operator is required to control both ingoing and outgoing work. The unit is compact and robust, and takes up very little floor space. The furnace illustrated has a rating of 36 kw. and gives an output of 2 cwt. per hour. Further examples of this type are shown in Fig. 7, which shows two rotary hearth furnaces; they are electrically heated, and when used in conjunction with G.E.C. town's gas burners, provide an atmosphere which gives clean heat-treatment without scaling or decarburising. These furnaces are being used for the general heat-treatment of steel parts for aero engines.

Fig. 9.—Battery of double deck natural draught gas-fired furnaces for refining and hardening aero engine parts.

Courtesy of Incandescent Heat Co., Ltd.



Courtesy of Metalectric Furnaces, Ltd.

Fig. 10.—Low-temperature recirculated atmosphere skip type furnace for the heat-treatment of light alloy rods.

Batch furnaces will always be popular and the modification of these to the bell-type of furnace is quite an economical proposition for many operations, notably in the bright annealing of brass and copper strip and wire. A typical installation of this kind is shown in Fig. 8, which illustrates two bell-type electric furnaces, each with four bases. The usable area of the bases is 4 ft. 6 in. diameter and 3 ft. high, while the furnace bells have a rating of 60 kw. A heat-resisting steel retort is provided for each base, each retort being corrugated to accelerate cooling. A centrifugal fan is fitted in the bases to ensure temperature uniformity and to shorten the heating-up period.

An interesting installation of batch furnaces is that shown in Fig. 9, which includes a battery of eleven double-deck natural draught gas-fired heat-treatment furnaces for refining and hardening of aero engine parts. The inside dimensions of the larger size furnaces are: Bottom chamber, 4 ft. 6 in. long, 2 ft. 6 in. wide, and 1 ft. high to crown of arch; and top chamber, 3 ft. 9 in. long, 2 ft. 6 in. wide, and 1 ft. high to crown of arch. The smaller furnaces have clear inside working dimensions 3 ft. long, 2 ft. wide, and 1 ft. high. Both chambers may be operated independently to any temperature up to 1,000° C., but they are rarely used for other than the general heat-treatment of aero engine parts at a maximum temperature of 870° C.

For the heat-treatment of certain products, a skip type furnace has many advantages, and the low-temperature recirculated atmosphere furnace of this type, shown in Fig. 10, is used for the heat-treatment of light alloy rods, tubes and sections. The furnace operates at temperatures up to 530° C. within limits of ± 3½° C. The skip is 16 ft. long, 2 ft. wide, and 1 ft. 3 in. high, and the approximate weight of each charge is 500 lb.

Gas carburising has made greater progress in the United States, but several furnaces designed to use gas as the carburising agent, instead of by the direct action of carbon, have been installed recently. When steel is heated it becomes permeable to gases, which diffuse into the steel. The effect of the gas on the steel will depend upon its composition, but when used for carburising the gas becomes a vehicle for carbon, and as the gas diffuses into the mass

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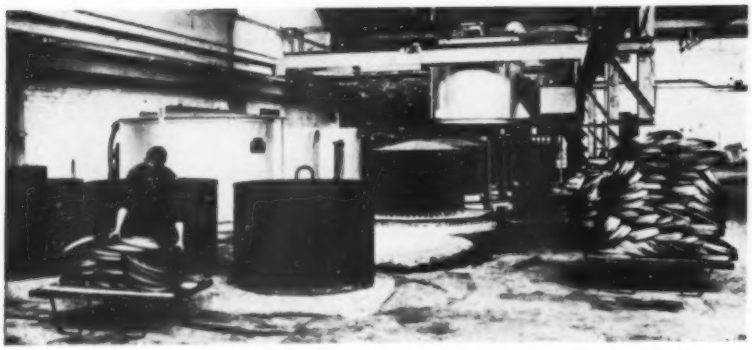
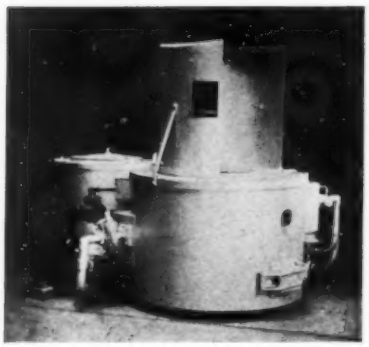


Courtesy of G.W.B. Electric Furnaces, Ltd.

Fig. 8.—Two bell-type furnaces, with four bases, for the bright annealing of non-ferrous wire and strip.



Courtesy of Cassel Cyanide Furnaces, Ltd.

Fig. 13.—Gas-fired salt-bath furnace with a preheater as part of the equipment.

of steel it decomposes and new quantities of carbon are taken up by the steel. By using a gas of suitable composition the action can be quickened and the process of carburising to a required depth can be effected economically.

By this method a carburised case of any specified depth in the carburising range is obtained uniformly and with reasonable results in the new "Homocarb" furnace shown in Fig. 11. This furnace is equipped with separate and fully automatic controls for temperature and for the amount of carburising medium. A specially prepared hydrocarbon oil is used, which, on entering the furnace, is converted into a gas rich in carbon and uniform in chemical composition. A high-pressure fan, located immediately below the work, causes this gas, at carburising temperature, to surround each part of the work being treated, and facilitates the development of a hard case.

A similar principle is applied to nitriding, in which nitrogen is the case-hardening medium. This process, for which a number of steels, known as nitriding steels, are commonly used, imparts a remarkable surface hardness without necessitating further treatment. In this process the parts to be treated are heated to the required temperature in the presence of ammonia gas and nitrogen is absorbed by the steel. The depth of case produced depends upon time and temperature factors, as well as upon the condition and composition of the steel treated. Wear resistance, retention of hardness at elevated temperatures, and resistance to certain types of corrosion, are among the properties imparted to steel by nitriding. The vertical cylindrical electric furnaces shown in Fig. 12 are installed at a large engineering works for stabilising and nitriding crankshafts with minimum distortion.

The salt bath is in common use for a wide range of heat-treatments. It provides a rapid method of heating work to be treated, as the bath can be maintained at a regular temperature, and this heat is absorbed by the work without contact with the furnace atmosphere. It is used for both

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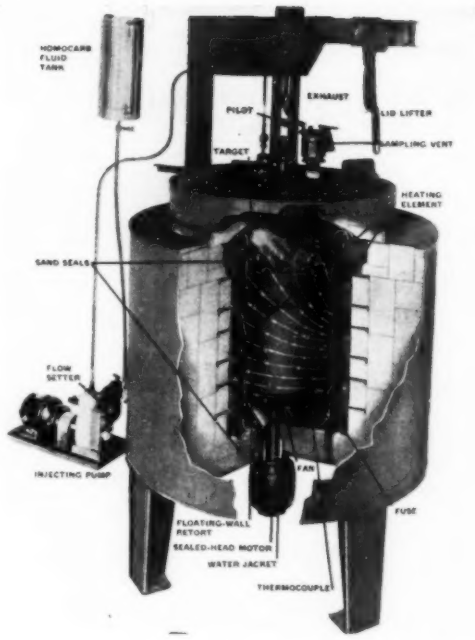


Courtesy of Integra Co., Ltd.

Fig. 11.—The new "Homocarb" carburising furnace.

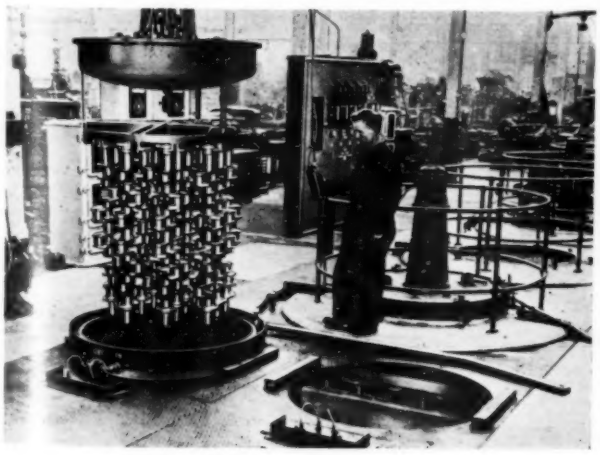
hardening and tempering steel, but it will be appreciated that plunging cold parts in a bath at the hardening temperature will set up stresses in the steel components, in the gas-fired furnace shown in Fig. 13, however, a preheater forms part of the equipment. Both the main furnace and the preheater, in this instance, carry the same size of pot—18 in. diameter and 24 in. deep—for the bath.

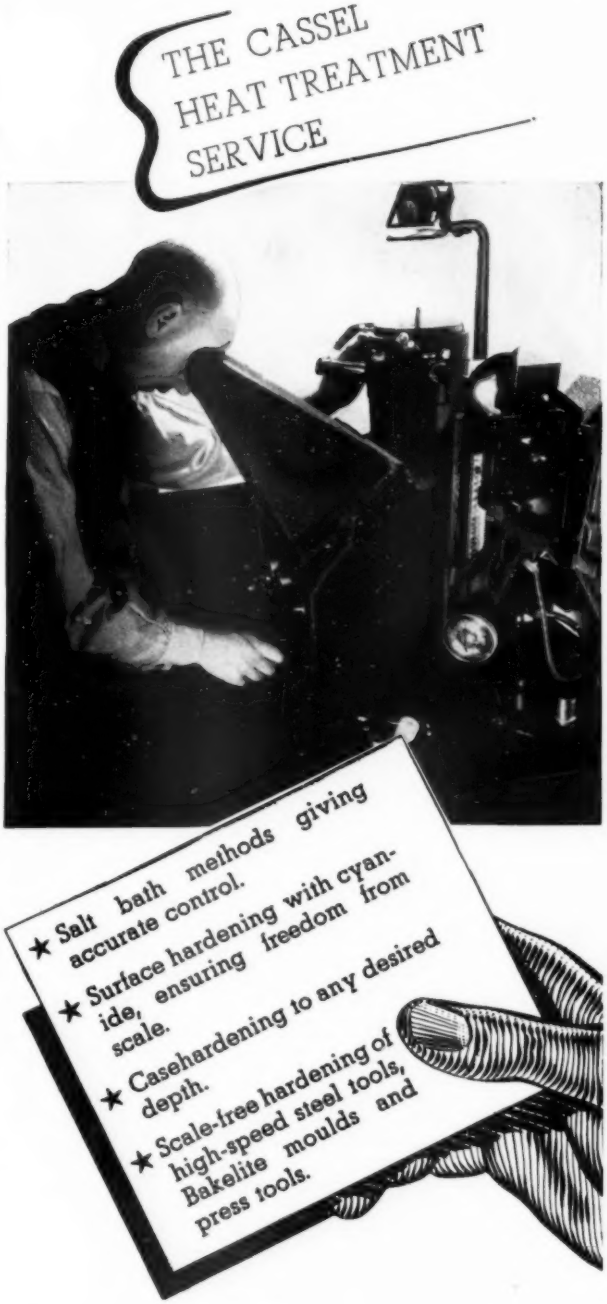
Salt baths are being increasingly used for the solution treatment of aluminium alloys. This treatment consists in heating suitable alloys at such a temperature as will facilitate the constituents going into solid solution, in which they are held by subsequent quenching. These baths are made in a wide range of sizes, and various heating mediums are employed. The natural draught salt-bath furnace shown in Fig. 14 is 5 ft. long, 3 ft. 6 in. wide, and 2 ft. deep, while much larger ones are shown in Fig. 15. These furnaces are used for the treatment of rolled sheet and large presswork; airframes, extruded sections, strips and bars; fabricated frames, sheets and pressings; tubes and rods; components, stampings and rivets. Air circulation furnaces are also used to a considerable extent for this form of heat-treatment, and among the many types

(*Continued on page 44*)

Fig. 12.—Vertical cylindrical electric furnaces for stabilising and nitriding crankshafts.

Courtesy of General Electric Co., Ltd.

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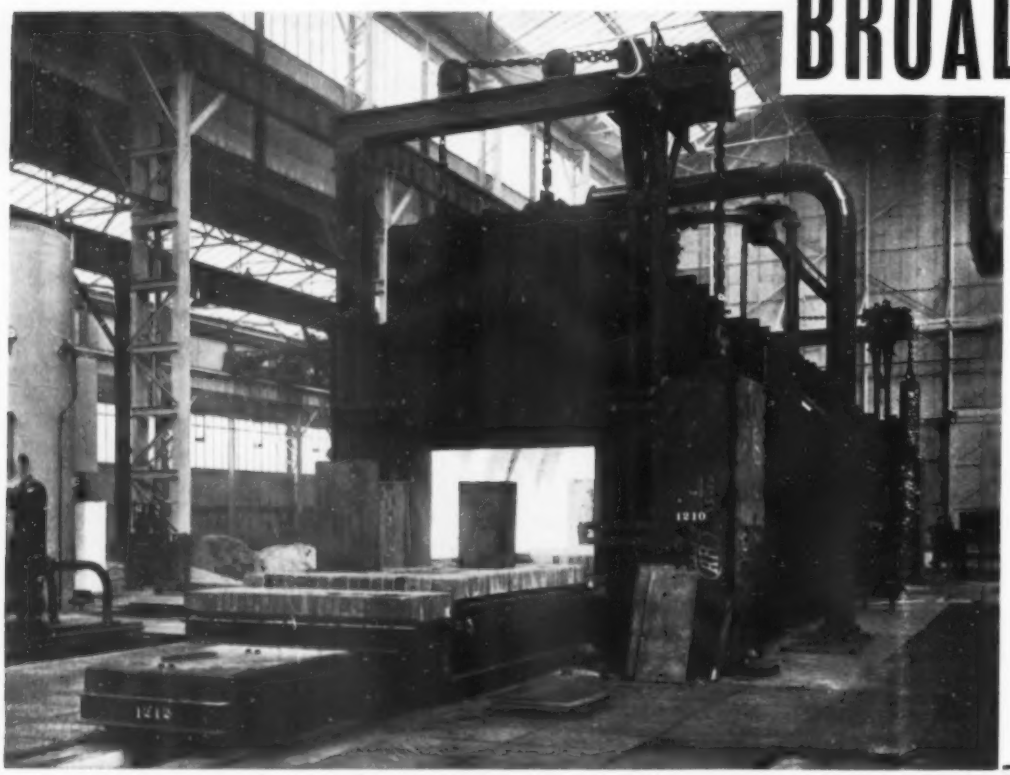

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The Fabrication of Magnesium Alloys

By L. G. DAY

Considerable progress has been made in the development of technique for the successful working of magnesium alloys; some of the operations involved were discussed by Mr. Day, in a recent paper before the Midland Metallurgical Societies, in which he referred to the melting of suitable alloys and discussed practical aspects of sand- and gravity die-casting, extrusion, forging and pressing, and rolling, the salient features of which are presented in this abstract.

THE success resulting from the various processes employed in working magnesium alloys is largely dependent upon the melting procedure and the subsequent casting. Magnesium alloys can be melted in gas, fuel-oil, coke-fired or electric resistance heated furnaces, the most economical and convenient, in this country, being the gas- or oil-fired furnace. The temperature required in the melt is of the order of 900° C., although the melting point of magnesium alloys is usually between 600° and 650° C. and further reference will be made to the comparatively high temperature of the melt.

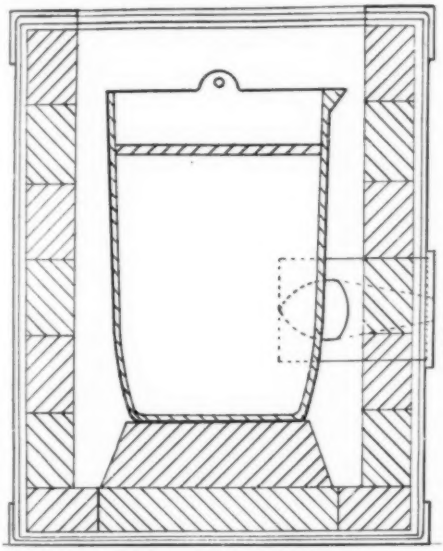


Fig. 1.—Section of typical lift-out type of furnace used for melting magnesium alloys.

Steel crucibles are commonly used and may be cast, formed by pressing, or fabricated from steel plates. Crucibles made from refractories are unsuitable as they are rapidly attacked by the metal and fluxes. Steels containing nickel are also unsuitable owing to the ease with which molten magnesium will dissolve this element. In general, a low-carbon steel is suitable for the purpose. The usual form of crucible corresponds to that of the standard refractory type and in general it is thought advisable to maintain a small diameter in comparison to the height of the crucible in order to expose as small a surface of the molten metal as possible to atmospheric oxidation effects. An illustration of a lift-out type of furnace and crucible is shown in Fig. 1. Similar principles hold good for tilting type furnaces. Such a type of crucible is suitable for sand-casting operations.

In contradistinction to the advised small diameter crucible is the bale-out furnace which is recognised as being most suitable for die-casting operations. Crucibles of such furnaces necessarily have a large superficial area, and, in this connection, a particular type of furnace has been developed and patented with a view to overcoming surface oxidation difficulties. Such a furnace is shown in Fig. 2. The principle involved is that of the exclusion of air by means of a hot gas shield over the working aperture and the replacement of air in the furnace by means of SO_2 gas. Any excess of this gas is drawn up the draught flue away from the operator. By such means the surface of the metal may be maintained free from oxidation for a period of several hours.

When melting magnesium alloys, the use of a suitable flux must be considered to be an essential. This is necessary to reduce oxidation and nitridation to a minimum and to remove from the melt, by means of a solvent washing action, all non-metallic impurities in suspension in the melt. These impurities are not separable either by means of liquation of flotation. The basis of all good magnesium fluxes is magnesium chloride. Many patents exist on combinations of this and other salts compounded as fluxes for magnesium, the principle of such mixtures being that not only must the flux remove oxide impurities from the melt, but that the flux and such impurities must be readily separable from the molten metal, as residual traces of such salts, which

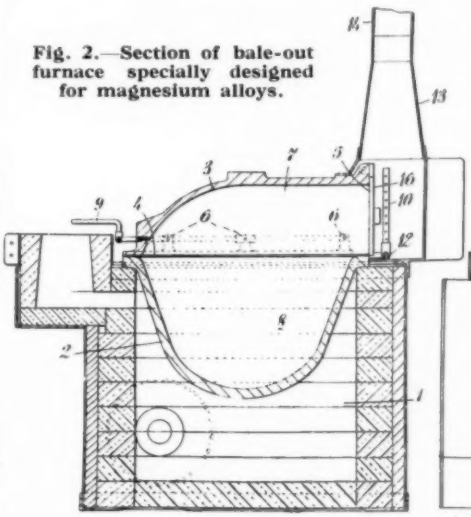


Fig. 2.—Section of bale-out furnace specially designed for magnesium alloys.

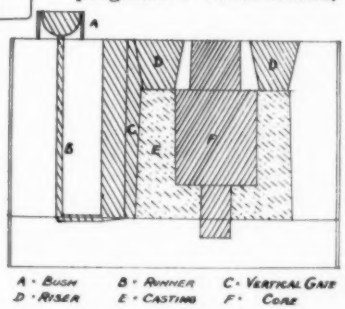


Fig. 4.—Showing gating arrangement to facilitate progressive solidification.

are usually of a hygroscopic type, would markedly accelerate corrosion in the finished article. This separation in the case of the lift-out or tilting type of crucible is usually effected by using a flux which, together with any absorbed impurities, will float on the surface of the melt, and, preferably, when so doing being subject to some oxidation which will enable the flux cover to form a hard or semi-hard crust. Cleaning is effected by vigorously stirring the flux when molten into the melt and then allowing it to rise to the surface.

In the case of bale-out furnaces previously described a different technique is adopted. The flux is desensitised by means of a heavy salt and caused to sink to the bottom of the pot after stirring for cleaning purposes. Separation of flux, metal and impurities in each case is effective.

Sand Casting

In this process precautions which are not necessary with other common metals have to be taken. Molten magnesium has an affinity for water with which it will react with explosive violence. The operation of skin-drying or stove-drying moulds frequently practised on other non-ferrous alloys is not sufficient for magnesium alloys as the molten metal will react with both the free

Fig. 3.—Defective castings resulting from reaction between the molten metal and the moisture content of their moulds.

and the combined moisture in the moulding sand and the clay bond. The result of such reaction will lead to unsightly oxidised spots on the casting, and, in severe cases, complete destruction of the casting by oxidation. Such attack marks are shown in Fig. 3.

In order to overcome this difficulty a chemical inhibitor is added to the moulding sand, the principle of this being to interpose an inert chemical layer between the metal and the moulding sand and clay. Several different types of chemical inhibitors have been discovered and processes involving the use of these have been patented. One well-known inhibitor is sulphur which is used in quantities of the order of 7 to 8% in combination with 1 or 2% of boric acid. Another is ammonium bi-fluoride. In the case of the first type of inhibitor the mould is filled with inert sulphur vapour and SO_2 when the molten metal contacts the sand. With the second type of inhibitor the stream of molten metal is covered with an inert fluoride skin. Both inhibitors are effective and can be used when casting into green sand moulds.

As molten magnesium has a low density, precautions must be taken to ensure that gases generated, during the casting operations, have free exit from the mould. This is best achieved by using a moulding sand with a high permeability. Most natural moulding sands do not possess this property to the degree desirable, and it is generally advisable to use a synthetic sand. Such sands are compounded from graded silica sand with an added clay binder. Bentonite, a colloidal clay is a useful material for this purpose. There are two main advantages attached to the use of synthetic moulding sands. First, the physical properties of the sand can be maintained constant, and second, the percentage of moisture necessary to effect a bond is much lower than is the case with natural sands.

It should be accepted as an axiom that the metal should enter the mould with as little turbulence as possible, as such turbulence promotes the formation of oxide skins which become entrapped in the casting. To this end the use of staggered downrights is often advisable. Downrights of rectangular section are preferable to circular ones as the formation of a vortex is prevented in this type of downright. Wherever possible, gating in such a manner that will allow of progressive solidification is advised, and an illustration of such a form of gating is shown in Fig. 4. Such a form of feeding is desirable in the alloys of of magnesium-aluminium series owing to the big interval between the liquids and the eutectic temperature.

Heat-Treatment

The alloys used for magnesium sand-casting are mainly those employing aluminium in the proportions of 8 and 10%, respectively. Both of these alloys can be subjected to heat treatment. The initial form of heat treatment is the same for both alloys, namely solution treatment at a temperature of 400° to 430° C., for a period of 20 to 30 hours. Alloys containing aluminium in excess of 9% are susceptible to precipitation hardening which can be carried out at 170° to 200° C. for a period of 12 to 20 hours. The first treatment which must be carried out in an inert atmosphere has the effect of increasing the ultimate tensile strength and elongation of the alloy, the second treatment increases the proof strength and hardness and considerably reduces the elongation. These increases and reductions in mechanical properties, however, are a function of the time and temperature of precipitation hardening. The three conditions of micro-structure are shown in Fig. 5. Table I gives a résumé of the mechanical properties of these alloys in their various conditions. The desirability of progressive feeding for alloys of the magnesium-aluminium type, emphasised earlier, is due to the long solidification interval, during which these alloys are particularly prone to inter-dendritic shrinkage, and it is this form of defect that is the main cause of porous magnesium castings.

In order to combat this defect an alloy has been developed by High Duty Alloys Limited, which is considered to be free from such weaknesses. This alloy has as alloying constituents tin, aluminium and magnesium, and it can be heat-treated. Its mechanical properties are also given in Table I.

Reference has been made to the necessity of superheating the melt to 900° C. With most common metals such superheating is considered undesirable and, certainly with aluminium alloys, results in gas absorption and coarse grain. With magnesium alloys the reverse is the case. No appreciable gas absorption has been observed, but by maintaining the metal at a temperature in excess of 850° C., for a period of about 15 minutes and allowing it to cool as rapidly as possible to casting temperature, a most marked grain refinement takes place. This grain refinement has a noticeable effect on the mechanical properties of casting alloys, particularly on those which are subjected to subsequent heat treatment.

Die Casting

By this definition is meant the process better described as gravity die-casting as opposed to pressure die-casting.

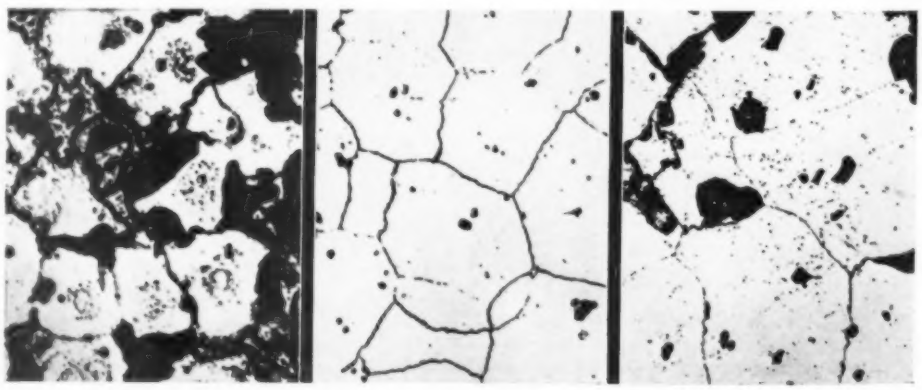


Fig. 5.—Micro-structure of a typical magnesium alloy in the as-cast, solution treated and precipitation hardened conditions.

The former is practised considerably in this country and the latter mainly on the Continent and in America. Magnesium castings can be made successfully by each process. The alloys used for gravity die-casting are the same as those used for sand-casting.

The dies for gravity die-casting are usually made from a good quality grey cast iron, cores being made of mild steel. It is possible to use these materials as magnesium has no eroding effect and the dies are only subject to normal wear and tear. Owing to the low latent heat of fusion of magnesium relatively little heat is imparted to the mass of the die during the casting operation and for this reason it is frequently necessary to supply heat to the die from an external source such as a suitable gas-burner in order to maintain the die at a suitable even working temperature. For the same reason dies should have a relatively light wall thickness in order to reduce the thermal losses to the die by conduction. Owing to the hot shortness of magnesium alloys, a liberal draft should be allowed on all sections where core extraction or die removal is necessary when extracting the casting. Sudden changes of section should be avoided and generous radii should be used.

Pressure die-casting in this material has not found great favour in this country, possibly owing to the fact that such castings always contain fundamental defects of the same type, namely blowholes and internal cavities.

Extrusion

Magnesium and its alloys can be readily extruded under suitable conditions to any reasonable form or section. The mechanical properties of the pure metal are low and extrusions in pure magnesium are usually only of small section and in the form of wire or ribbon such as may be used for pyrotechnic or chemical processes. Extrusion is always carried out hot, the ingots being pre-heated in an electric of gas-fired air circulated muffle to a temperature of the order of 350° C. They are placed in the container of the press, which is also maintained at about the temperature of the preheated ingots. Extrusion speeds vary with the dimensions of the material being extruded, as an example, a speed of 12 to 14 feet per minute can be achieved on bar 1½ in. diameter. Extrusion at a faster speed will result in overheating the bar due to the heat generated by the energy of extrusion. Over-heating causes surface oxidation. A 900-ton extrusion press is capable of extruding bar and sections from 8-in. diameter ingot to sizes from ½ in. to 3 in. diameter or equivalent cross sectional areas. Round bars are usually straightened after extrusion by cold rolling, but care must be taken that no appreciable reduction in area takes place by this process as the material is extremely susceptible to cold work and a hard laminated skin would result.

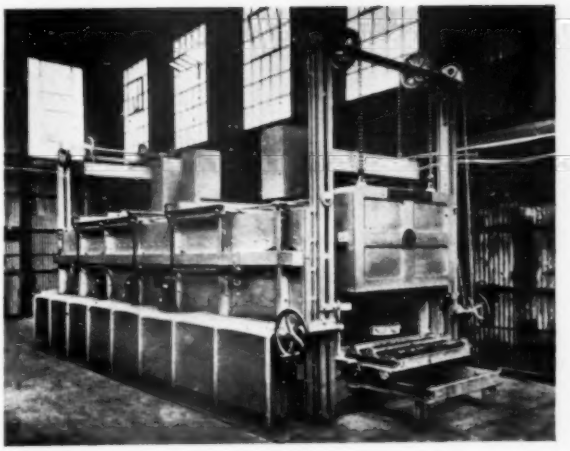


Fig. 6.—An electric resistance furnace for preheating forging ingots.

Forging and Pressing

With suitable technique magnesium alloys, of similar chemical composition to those used for extrusion may be forged, pressed or drop stamped. Each of these operations must be carried out on metal pre-heated to a suitable temperature usually of the order of 380° to 400° C. The pre-heating is carried out in an electrically resistance heated or gas-fired air-circulated oven furnace. It is customary to commence breaking-down operations from the cast structure at the higher temperature and finish working at the lower end of the range as by these means maximum mechanical properties are developed in the material.

Nearly all forging is carried out under hydraulic presses, swages and plates which can be maintained at forging heat, but the method of open hammer forging is seldom applied to magnesium alloys as maximum deformation is obtained when the flow is maintained in one direction. Drop forgings are usually made from suitable extruded or press swaged stock. All magnesium alloys are extremely sensitive to cold work and no major operations can be carried out below 250° C. without serious risk to developing cold working defects. No improvement is brought about by heat treatment after forging, the optimum properties being those of the as-forged or as-pressed material. One of the most interesting developments in the utilisation of worked magnesium is that of the press-forged air-screw blade which to date has given very satisfactory results. Fig. 6 shows an electric resistance furnace for the pre-heating of forging billets.

TABLE I.

MAGNESIUM CASTING ALLOYS.

ALLOY COMPOSITION AND MECHANICAL PROPERTIES IN AS-CAST AND HEAT-TREATED CONDITION.

Alloy.	Composition % Magnesium Remainder.	Specification and Condition.	Mechanical Properties.			
			0.1% Proof Stress Tons/in.²	Ultimate Tensile Strength Tons/in.²	Elongation % on 2 in.	Brinell Hardness.
Magnuminium 181	Al—8.5 max. Cu—0.4 max. Zn—3.5 „ Pb—0.4 „ Mn—0.5 „ Fe—0.1 „ Si—0.4 „ Sn—0.4 „	Spec. DTD. 59A. as cast	4.0–5.0	9.0–11.5	2–8	45–55
		Spec. DTD. 289 soln. treated ..	4.9–5.0	13.5–15.5	8–12	45–50
Magnuminium 220	Al—9.11 Other impurities 1.0 max. Zn—1.0 max. Mn—0.5	Spec. DTD. 136A as cast	4.5–5.5	9.0–11.0	2–4	50–60
		Spec. DTD. 281 soln. treated ..	5.0–6.5	14.0–16.0	5–10	50–55
		Spec. DTD. 285 soln. treated and aged	7.0–9.5	15.0–17.5	1–4	85–105
Magnuminium 299	Al—2.0 – 6.0 Mn–0.6 max. Sn—3.0 –10.0 Other impurities 0.5 max. Ag—0.25– 4.0	Spec. DTD. 350 as cast	4.0–5.0	10.0–12.0	5.0– 9.0	
		Spec. DTD. 360 heat-treated ..	4.0–5.0	12.0–14.0	7.0–10.0	

Rolling

Magnesium alloys with up to 6% of aluminium may be readily rolled, but, as with pressing and forging, all operations down to the finishing passes must be carried out at elevated temperatures. For this reason the rolls must be capable of being maintained hot. Provided this is done, fairly heavy reductions as high as 25% may be made in the initial breaking down stages. This draft, however, is considerably reduced as the material gets progressively thinner. If the material is maintained at working temperature through contact with the hot rolls, long period intermediate anneals are unnecessary. Sheets up to 36 in. wide by 120 in. long are regularly produced in gauges from 12 to 20 and narrower widths to 24 gauge. Two alloys are mainly used for sheet production, these being magnesium with 1 to 2% manganese, and magnesium with 4 to 6% aluminium. The mechanical properties of the former alloy are from 11 to 14 tons per sq. in., ultimate stress and that of the latter from 16 to 18 tons per sq. in. Magnesium alloy sheet may be fabricated by means of bending, beating and welding. Welding can be freely carried out on magnesium sheet with an oxy-acetylene or oxy-hydrogen torch, oxy-acetylene being more commonly used.

Effect of Atmosphere During Melting and Casting of Copper*

By Prof. C. R. Hayward, Prof. M. Isawa, and Prof. E. M. Thomas

Experiments are described on the melting and casting of copper under various conditions, on a scale designed to be readily producible under plant conditions, with the object of throwing further light on the causes of unsoundness in cast copper and to suggest better procedures in practice. A brief summary of the paper is given, and also the authors' discussion of the conclusions arrived at as a result of the tests made.

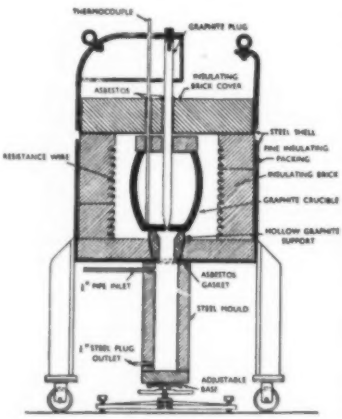
ALTHOUGH there is complete agreement regarding the phenomena which occur during the standard operations in oxidising and poling molten copper, and the precautions which are necessary to meet the requirements of the trade, a considerable difference of opinion develops when an explanation of these phenomena is attempted. This is particularly true when the porous condition and convex surface of the casting, which result from overpoling, are obtained.

This condition is obviously due to gases, but in spite of considerable research and discussion, there is no general agreement as to the nature and origin of these gases. The most convincing arguments have been those of Allen,[1] who published the results of an extensive research in 1930. In most of this latter work the quantity of copper used was only 200 grm., and in the small apparatus used Allen was able to ensure accurate manipulation and consistent results. The purpose of the present experiments was to melt and cast copper under various conditions on a scale which, although far from being a commercial size, would nevertheless give results which might be readily reproducible under plant conditions. It was hoped that the phenomena observed would throw further light on the causes of unsoundness in cast copper, and suggest better procedures for copper refineries and foundries.

The procedure used in these experiments was to melt cathode copper under a cover of charcoal in a graphite crucible, heated electrically, and cast it in a vertical steel mould through a ½ in. bottom tap in the crucible. The tap-hole was closed by a graphite rod which extended through the top of the furnace. Various gases were used to fill the mould and the space below the crucible. A section of the furnace, with the mould in place, is shown in next column. Specific-gravity determinations were made on the resulting copper ingots, and a few samples were drawn into wire for further testing.

The first experiments were made by using a steel mould with a square cross-section, the billet produced was 1½ in. square in section and weighed 10 lb. After a series of tests with this mould, a second steel mould was used, from which billets 3 in. square and 30 lb. in weight were produced. In all melts, with few exceptions, the crucible was placed in the furnace when cold and charged with the cathode copper, a liberal amount of charcoal being placed on the top. The crucible was not covered, but the top of the furnace was closed. The current was turned on, brought to a maximum in about 30 mins., and then kept constant until the final temperature was reached.

When the desired casting temperature was near, the air in the mould was displaced by the gas which it was proposed to use, and the lower opening in the mould closed by a pin. The graphite plug was then raised, and the metal allowed to enter the mould. The gas continued to flow through the upper side opening into the mould during the casting. Billets were cast in air, city gas, nitrogen, carbon dioxide, and hydrogen. The gases were dried by passing through a calcium chloride tower, while hydrogen and nitrogen were also passed through pyrogallol solution to remove oxygen.



Section of experimental furnace

The test results show clearly that cathode copper melted quietly under charcoal in the absence of combustion gases or other gases, except those derived from the hot charcoal, may be cast in an atmosphere of nitrogen, hydrogen, carbon dioxide, or normal illuminating gas, to give a billet of high density and low oxygen content. When cast in air, however, in the manner described, a billet is produced of relatively low density, having an appreciable oxygen content.

In a second part of this paper various tests are described in which the gases in contact with the copper during melting were varied, and the atmosphere in which the copper was cast was, in general, hydrogen. A few exceptions to this procedure were made to confirm certain points. In these experiments the amount of metal used in each test was 20 lb., instead of 30 lb., since excessively swelled tops on some of the billets were anticipated.

Discussion of Results and Conclusions

There is no serious conflict between the results obtained in this work and those presented by Allen and certain other investigators, as far as the behaviour of hydrogen is concerned. It has been shown that when present in considerable concentration in the furnace atmosphere, hydrogen is

* *Jour. Inst. of Metals*, **66**, part 1, pp. 109-129.
1 N. P. Allen. *Jour. Inst. Metals*. 1930. **43**, p. 81.

readily absorbed and will cause a porous billet when the metal is cast fairly rapidly in a mould filled with hydrogen. When the hydrogen-treated metal is cast in air, the porosity of the billet is increased as a result of the reaction between hydrogen and oxygen. This is probably mainly a secondary reaction, the oxygen forming cuprous oxide, which in turn reacts with hydrogen. This delayed evolution of the gas produces serious swelling in the billet head.

For short periods of time, moderate concentrations of hydrogen in the furnace atmosphere have little effect on the soundness of billets cast in inert or reducing gases. No tests were made to study absorption over periods of time beyond 15 mins., although it seems reasonable to suppose that the effect of time would be an inverse function of hydrogen concentration.

The effect of carbon monoxide in the furnace atmosphere on unsoundness is negligible if the copper is to be cast under reducing conditions. If cast in air there may be a reaction between carbon monoxide and cuprous oxide or atmospheric oxygen to cause some porosity. Since carbon dioxide is reduced to carbon monoxide when the copper has a charcoal cover, it is obvious that carbon dioxide in the furnace atmosphere may be neglected.

The influence of sulphur dioxide is of great importance. It readily dissolves in, and reacts with, molten copper during casting; in the presence of a charcoal covering on the molten copper in the furnace it is reduced to sulphur, which reacts with the copper to form cuprous sulphide. If the copper containing cuprous sulphide is cast under reducing conditions, this compound remains as such in the metal and a sound billet is produced, but if the copper is cast in air the cuprous sulphide reacts with atmospheric oxygen or cuprous oxide and sulphur dioxide is evolved, producing unsoundness.

When copper, melted under charcoal and therefore very low in oxygen, is poled with green twigs, the billets produced are very unsound. The nature of the gases was not determined, but in view of the known conditions and the results of other tests it is fairly safe to assume that the unsoundness is due to hydrogen.

Other investigators have shown that nitrogen has little or no solubility in copper and may be used to displace other gases. This was confirmed in the present tests. It was further shown that the introduction of an atmosphere of nitrogen over molten copper in which large amounts of hydrogen are dissolved is sufficient to allow the hydrogen to diffuse out of the copper to a point where a sound billet will be produced if cast under reducing conditions.

One of the most interesting observations in the above tests was the rapidity with which oxygen is taken up by the copper during casting. In the very short interval during which the copper was running from the crucible to the mould, the oxygen had an important effect on it, and made the difference between up to 2 bends after the hydrogen anneal, and 10–12 bends. This rapidity of attack was also noted in the case of sulphur dioxide. Since the copper was cooling rapidly, hydrogen in the mould was not absorbed.

From the above observation the following comments on copper refining operations seem justified:—

(1) When the oxygen becomes low in the copper, the bath will absorb considerable quantities of hydrogen, either directly from the furnace atmosphere and the poles or through reduction of water vapour from the atmosphere and poles by hot carbon. There will be some, but considerably less, absorption of carbon monoxide, either directly from the furnace atmosphere or through reduction of carbon dioxide by hot carbon. There may be some absorption of sulphur dioxide, but most of the gas will probably be reduced to sulphur by hot carbon and form cuprous sulphide. The sources of sulphur are the furnace atmosphere, the charcoal or coke, the cathode copper, and the poles.

(2) If low-oxygen copper, produced in the usual way in fuel-fired reverberatory furnaces and reduced by poling, is cast under oxidising, reducing, or neutral conditions it will always be unsound owing to the large amount of dissolved gases; the unsoundness will, however, be greater when it is cast in air, due to the formation of cuprous oxide, followed by its partial reduction by hydrogen and carbon monoxide.

(3) The principal source of hydrogen in the copper is undoubtedly the poles. It might be possible to eliminate a considerable part of it by allowing the copper to stand for a period after the poling is completed, to give time for diffusion of hydrogen from the bath to the furnace atmosphere. Decreasing the temperature would also be helpful.

(4) Melting cathodes by continuous feeding beneath the bath in an electric furnace without poling should give a minimum of gases in the molten copper, and casting under reducing conditions in a manner similar to that used by the producers of O.F.H.C. copper should give maximum soundness and minimum oxide content. Even the small amount of air in the mould should be displaced if the best results are to be obtained.

Journal of the Institute of Metals, Vol. LXV. 1939.

THE latest volume of the above Institute, just published, is the largest issued in the last 10 years. It contains 27 papers, practically all of them embodying the results of original research, and covering almost the whole field of non-ferrous metallurgy. Looking through the contents list, one is struck by the large proportion of papers which are of direct interest and importance to the practical metallurgist, and which will amply repay his study.

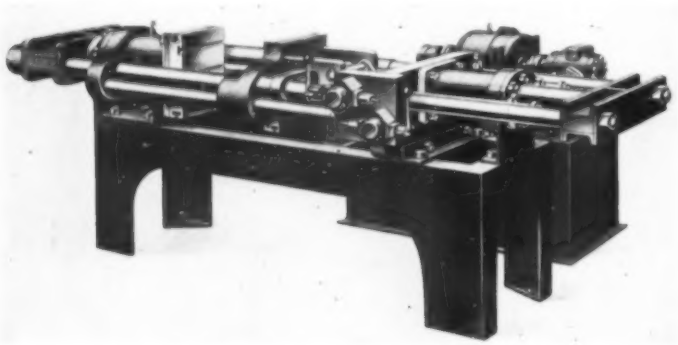
Papers on "The Anodic Oxidation of Aluminium," by J. W. Cuthbertson; "The Diffusion of Oxygen in Copper," by C. E. Ransley; and "The Direct Oxidation of Zinc," by W. H. J. Vernon, E. I. Akeroyd, and E. G. Stroud, all give accounts of exhaustive and painstaking research of the highest standard. Engineers should find valuable data in the paper by J. W. Donaldson, on "The Thermal Conductivities of Some Industrial Alloys of Copper and of Nickel," and in W. A. Baker's paper on "The Creep Properties of Soft Solders and Soft Soldered Joints." The latter, and a paper on "The Determination of Oxygen in Metals," also by Mr. Baker, came from the laboratories of the British Non-Ferrous Metals Research Association. The work of two other important centres of metallurgical research—the National Physical Laboratory and the Research Department, Woolwich—is represented in this volume, the first by two further papers on magnesium alloys by J. L. Haughton, and the second by two papers by L. Northcott: "The Influence of Alloying Elements on the Crystallization of Copper—II," and "Dendritic Structures—I."

The volume contains another contribution on the apparently limitless subject of the age-hardening of aluminium alloys, this time by Mm. Calvet, Jacquet, and Guinier. Drs. Price and Thomas follow up their important work of a year or so ago on the protection of silver, with a short paper on "The Protection of Silver by the Electrolytic Deposition of Beryllia," a process which would appear to have interesting potentialities. On the more purely theoretical side, there is a provocative paper on "The Nature of Certain Intermetallic Lattices," by A. L. Norbury. There are also papers on the constitutions of half-a-dozen alloy systems by eminent research workers, and the volume is completed by the text of the Autumn Lecture on "Aluminium and Highland Water Power," which Mr. Murray Morrison was unfortunately unable to deliver owing to the cancellation of the Glasgow meeting. We can say without hesitation that both the scientific content and the actual production of this volume, maintain the reputation of the *Journal of the Institute of Metals*.

Edited by S. C. Guillan. Demy 8vo. Pp. 480; with 60 plates and numerous illustrations in the text. London: The Institute of Metals, 4, Grosvenor Gardens, S.W. 1. 31s. 6d. net.

A New Hydraulic Machine for Die-casting Aluminium and Brass

WHEN the quantities required of any particular casting are beyond a certain minimum, the question of die-casting them becomes an economical proposition, especially if the products are required in some metal or alloy having a relatively low melting point. Many non-ferrous alloys are cast by the gravity die-casting process, but when the castings are desired in bulk quantities of 5,000 and upwards there is definite scope for the pressure die-casting process. This process is generally applied to the production of castings in the alloys of aluminium, zinc, copper, magnesium and lead, and a very high degree of accuracy of dimensions is obtained.



The Edgwick Pressure Die-Casting Machine.

Briefly, the process consists of forcing molten metal at high pressure and high speed into a die, one half of which is fixed and the other half movable. When the two halves of the die are opened the casting is removed by ejector pins. When a machine for this process was first introduced the pressure chamber was submerged in a melting pot incorporated in the machine, a piston forcing the metal from the pot into the die. These machines are still used successfully for the pressure die-casting of metals having a low melting point.

To the casting of brass and aluminium the higher temperatures involved presented difficulties in the adoption of this method which were overcome by the introduction of the cold-chamber machine. With this latter type of machine the metal is melted in an auxiliary bale-out furnace and ladled to the machine by the operator. Usually a crucible type of furnace is used.

A new machine of this type has recently been introduced by Alfred Herbert, Ltd. This machine, which is here illustrated is the Edgwick Full Hydraulic Cold Chamber Die-casting Machine for aluminium and brass. It has been designed in collaboration with T. H. and J. Daniels, Ltd., Stroud, the well-known makers of presses and equipment for the plastics industry.

Separate hydraulic cylinders are fitted for opening and closing the dies, and as the cylinders are single-acting, oil leaks through packing glands are reduced to the minimum. With this arrangement a large cylinder giving a high locking pressure can be used to keep the dies closed, and only a small cylinder is needed for opening the dies, thus economising in the amount of oil required. Both cylinders and pistons are carried on massive tie bars, the opening and closing movements being controlled by the ball-ended lever shown on the left in Fig. 1.

In operation, the dies are closed by moving the lever to the left. Metal is ladled from the bale-out furnace into the pouring chamber, which is arranged for water cooling, and the lever controlling the injection cylinder is operated. An important feature is that the die-closing lever and injection lever are interlocked, so that it is impossible to make the injection stroke until the dies are properly closed. The movement of the injection plunger is accelerated by means of a nitrogen-charged accumulator. Oil is forced into the accumulator at high pressure, which compresses the gas. When this oil is released to the injection cylinder the nitrogen expands quickly and a rapid stroke is imparted to the plunger.

The size of the die plates is 16 in. by 11 in., and the maximum projected area of casting which can be dealt with is 13½ sq. in. at 7,400 lb. pressure per sq. in. Castings of larger areas can be produced, using lower pressures and larger plungers.

The field for die-casting is continually increasing. The process is used extensively in the motor-car, aircraft, wireless, telephone, electrical, cinematograph and camera industries and many other trades where components are required in large quantities.

In addition to this new machine, Alfred Herbert, Ltd., are sole agents for the Reed Prentice Corporation, range of machines for die-casting alloys of zinc, aluminium, brass and magnesium, and also supply a complete range of equipment for the rapid and economical production of dies and moulds.

Electro-Magnetic Relays

RELIABLE relays for all electric control purposes are essential in modern industrial plants, and Londex Ltd., Anerley Works, Anerley Road, London, S.E. 20, inform us that they are manufacturing relays up to 50 amps. triple-pole switching capacity. There are several types, two of which may be referred to here: one is a heavy-duty type for contacts up to three single-pole mercury switches, or two change-over mercury switches, and a heavy-duty type multiple contact.

All the relays of the former type have a highly efficient magnetic circuit. The core and tilting armature are made throughout of laminations of high-grade magnetic material. The coils are continuously rated, suitable for up to 600 volts A.C. or D.C., or, in the case of current coils, for up to 50 amps. direct. The coil consumption is extremely low, being only two VA on A.C. and one watt on D.C. For A.C. excitation the relay is fitted with shaded poles with highly-polished surface to secure the silent working. Due to the efficient design of this relay, ample power is available to operate the several heavy-duty mercury switches. The simple tilting principle enables the "on" and "off" positions to be clearly seen. Further, the relays can be fitted with mercury switches to "make" or to "break" or to change over as required.

Special forms of these relays are available, for push-button control and delayed operation. Above 6 amps. switching capacity, mercury switches are used where, between the electrodes, a strong porcelain liner is fused into the glass tube. This construction provides the mechanical strength of the switch and gives complete arc protection. This type of switch is completely suitable for switching high voltages and direct-current circuits.

The main application of the multiple contact relay referred to above is in the control of a number of circuits, either straight switching or change over. For loads up to 300 VA A.C. or D.C., silver contacts are used, but by fitting tungsten points, the relay can control up to 900 VA loads. The standard design is suitable for use on 250-volt circuits, but for higher pressures, up to 500 volts, a special type is available. The former has a laminated tilting armature, and the shaded poles with a polished surface give silent operation. The coil has a consumption of only two VA, and can be wound for any voltage between two and 500. It is continuously rated, and is suitable for use on A.C. or D.C. It is arranged for two-hole fixing, and can be supplied bare or with a sheet-metal cover on an insulated base; cast-iron and sheet-metal casings are also obtainable. The weight of the relay without casing is 11 oz.

The Damping Capacity of Steel and its Measurement

An account is given of experiments to study the influence of moderate temperatures on the damping capacity of a series of typical steels. The Föppl-Pertz apparatus, modified so as to employ an optical recording device, was used for the measurement of damping capacity. Particular attention was given to a consideration of the effect on damping capacity of factors such as the initial stress, bending, size and shape of specimen. The Report of this work, which constitutes paper No. 1/1940 of the Alloy Steels Research Committee, was presented at the May meeting of the Iron and Steel Institute. In this article it is briefly reviewed and the author's conclusion given.

AN account of work on the influence of temperature upon the acoustical properties of steel was published by Robin[1] in 1911. By determining the time during which the sound produced by striking a bar of the material a standard blow could be heard, curves were obtained which showed marked abnormalities. Since the decay of the sound would appear to be closely analogous to the damping of a mechanical vibration, it appeared reasonable to suppose that measurements of "damping capacity" as a function of temperature might well be employed to investigate the "low-temperature abnormalities" of steel. The present work, by Dr. G. P. Contractor and Dr. F. C. Thompson, was, therefore, undertaken to examine the influence of moderate temperatures on the damping capacity of some typical steels of different heat-treatments and chemical composition.

It has been shown, however, that damping capacity is a property of a super-sensitive nature, and unless the test-pieces are produced from materials almost ideally identical with regard to the previous history and source of supply, the results may vary greatly, even when the ordinary composition is much the same. There are, further, several potential sources of error in the apparatus, and it appeared essential to examine these in detail before proceeding to the real subject of the research. The first part of this paper deals, therefore, with the actual measurement of damping capacity in a machine of the Föppl-Pertz type. It is evident that the results are of real significance if, and only if, the energy losses in the apparatus can be reduced to a point where they are small in comparison with those in the specimen itself. With the machine as finally devised, a series of observations on two specimens of identical material machined under carefully standardised conditions have given results which vary by only 1–3%.

When a body is set in free vibration, and even after all external forces—e.g., the resistance of the air, the frictional resistance of bearings, etc.—have been eliminated, there is still a continuous decrease of amplitude with time, the system ultimately reaching a state of rest. Briefly, "damping capacity" is that property of the material which causes these vibrations to disappear. Although the general idea is far from new, the term "damping"—as applied to metals in torsion—appears to have been first introduced by Föppl[2] in 1923, who defined it as "the amount of work dissipated as heat by a unit volume of a material during a complete reversed cycle of unit stress," and expressed it as the "specific damping capacity," P%. Different investigators have, however, given various names to this property. In the present paper the term "specific damping capacity," denoted by P, is used.

When a material is subjected to a cycle of stress below the "elastic limits," it is now generally appreciated that a hysteresis loop is obtained. The damping of the material may also be defined as the energy dissipated per unit volume, per cycle—i.e., by the area of this loop. If the material were perfectly elastic between the limits of stress employed, there would clearly be no loop and the damping capacity would be zero.

The authors discuss methods of expressing damping capacity and also factors influencing damping. Of the methods available for the measurement of damping capacity, the free vibration method appeared to be especially suited to this investigation. The apparatus employed was constructed on the general lines of the Föppl-Pertz machine,[3] shown in Fig. 1. Apart from an optical recording system, probably the most important modification of Föppl's machine was in connection with the pivot supporting the swing-bar and the upper end of the specimen, for which a self-aligning journal was substituted.

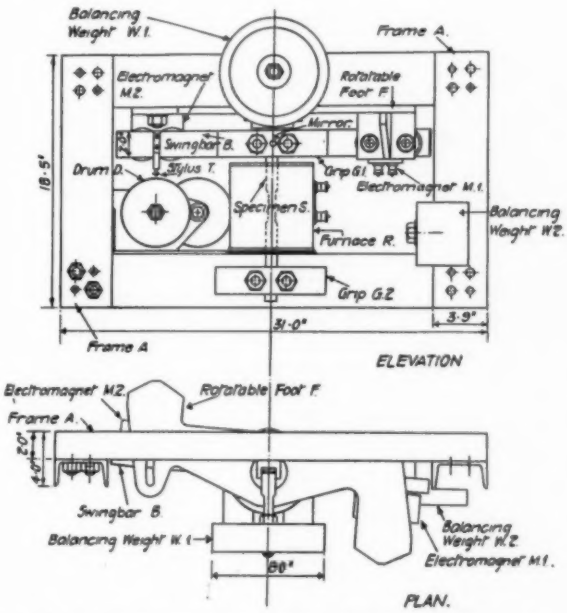


Fig. 1.—The apparatus employed in the experiments

The results of the investigation are presented as a contribution to the study of the problem. The authors emphasise that the scope of this work covers only the collection and, to some extent, the correlation of experimental data with regard to the damping capacities of a few steels at moderate temperatures, and that it would be premature at the present time to draw conclusions in terms of any fundamental theory; however, some noteworthy conclusions are submitted. The authors confirm the absolute necessity of suspending the whole apparatus as freely as possible, and refer to several other points in the measurement of damping capacity which need careful attention if accurate results are to be obtained.

In all but a few exceptional cases, the damping-capacity/fibre-stress curves rise with increasing stress.

1 Robin: *Iron and Steel Institute, Carnegie Scholarship Memoirs.* 1910. Vol. 2, p. 1.

2 Föppl: *Verein Deutscher Eisenhüttenleute.* 1923. *Werkstoff Bericht No.* 36.

3 Föppl: *Journal of the Iron and Steel Institute.* 1936. No. II, p. 393.

The question then arises as to the probable value of P for zero stress. It is shown that at stresses as low as 500 lb. per sq. in., and, in one or two instances, even down to 200 lb. per sq. in., the damping capacity measured has a definite, positive value. It is, therefore, clear that either a value around 0·4% represents the total of the experimental errors in this work, all of which would act in the same direction and increase the measured value of P, or that all of the materials examined give a mechanical hysteresis loop for all stresses, however low.

The exceptions to the normal curve, giving decreasing values of P as the stress rises are the following: (*a*) When the apparatus is standing on a table, and (*b*) when the specimen is only loosely gripped in the machine—both cases in which successive energy is lost during test; (*c*) the 0·2 and 0·9% carbon steels at temperatures above that at which the damping capacity undergoes a fairly sudden and relatively enormous increase; and (*d*) the vacuum-annealed Armco iron at fibre stresses above 9,000 lb. per sq. in.

Both the radical change in the shape of the curve and the variation of the temperature at which it occurs in different steels indicate clearly that it is not merely a question of exceeding the "elastic limit," but apparently of some inherent change in the properties of the material. If the behaviour of Armco iron and the 0·9% carbon steel, for instance, are considered in relation to the values of their limits of proportionality and the initial stress of 8·7 tons per sq. in., the former is stressed much above its elastic limit—about 4 tons per sq. in. at 300° C.—by the initial stress and yet shows no signs of the reversal of the curvature, whilst the 0·9% carbon steel, on the other hand, which has not been stressed up to its limit of proportionality, shows a clear reversal at a temperature around 300° C.

That there is, however, apart from the Armco iron, some general relationship between the ordinary mechanical properties and the temperature at which the change occurs will be evident from Table I.

TABLE I.

RELATION BETWEEN ORDINARY MECHANICAL PROPERTIES AND THE TEMPERATURE AT WHICH THE CHANGE IN DAMPING CAPACITY OCCURS.

Material.	Condition.	Temperature, ° C.
0·4% carbon steel	Cold-rolled	330
Armco iron	As received	> 310
3% nickel steel	Quenched and tempered	> 310
0·9% carbon steel	As received	> 310
0·4% carbon steel	Quenched 700° C.	> 310
0·4% carbon steel	First anneal	290
0·2% carbon steel	As received	270
0·4% carbon steel	Third anneal	270
0·4% carbon steel	Fifth anneal for 15 hours	250

For a given stress low-carbon steels have higher damping capacities than harder ones. Broadly speaking, the damping at room temperature decreases as the carbon content

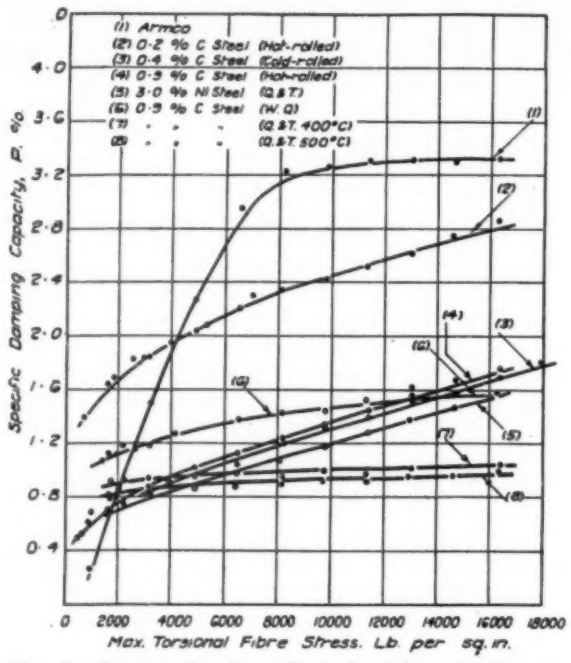


Fig. 2.—Curves showing effect of carbon content on damping capacity

increases, provided the material is similarly heat-treated (Fig. 2). There is good reason to believe, however, that factors such as grain size, structure, surface decarburisation, and the previous history of the material also influence the results.

As a result of the overlapping of the curves, however, it is not possible to place the materials investigated in any definite order so far as their damping capacities are concerned unless some arbitrary value of stress is chosen. In Table II typical results for a range of stress and at three different temperatures have been collected. These all apply to determinations carried out, as has been mentioned previously, with a constant initial stress of 19,560 lb. per sq. in. and a fibre stress of 13,000 lb. per sq. in. The consistently high values for the iron, and the low ones for the sorbitic nickel steel will be evident.

Passing on to consider the damping properties of the different constituents of steel, it will be seen from Table III that the martensitic sample had at room temperatures and for the lower stresses a higher value of P than that corresponding to the pearlitic state. At higher temperatures, however, this no longer holds. Not only is the damping capacity associated with the troostitic and sorbitic structures low, but it also remains relatively constant at high and at low stresses. For example, in the case of the sorbitic 0·9% carbon steel, P at stresses of 2,000 lb. and 16,000 lb. per sq. in. is 0·82% and 1·0% respectively.

TABLE II.

TYPICAL RESULTS FOR THE DAMPING CAPACITY AT DIFFERENT TEMPERATURES FOR A RANGE OF STRESS.

Material.	Condition.	Maximum Fibre Stress, Lb. per Sq. In., at—								
		20° C.			110° C.			230° C.		
		5,000.	10,000.	14,000.	5,000.	10,000.	14,000.	5,000.	10,000.	14,000.
		Damping Capacity, %.								
Armco iron	As received	3.08	4.10	4.11	3.60	4.62	4.75	4.06	5.07	5.23
0.2% carbon steel	As received	2.07	2.45	2.69	3.44	3.84	4.00	3.00	3.60	3.72
0.3% carbon steel	Normalised	1.24	1.72	1.98	1.40	1.86	2.09	2.19	2.64	2.80
0.9% carbon steel	As received	1.06	1.37	1.63	2.14	2.50	2.74	2.26	2.71	2.94
0.3% carbon, 3% nickel steel.	Quenched and tempered	0.90	1.19	1.43	1.15	1.47	1.69	1.90	2.28	2.52

TABLE III.

DAMPING PROPERTIES OF THE DIFFERENT CONSTITUENTS OF STEEL FOR A RANGE OF STRESSES AT THREE DIFFERENT TEMPERATURES.

Material.	Heat-treatment.	Maximum Fibre Stress, Lb. per Sq. In., at—								
		20° C.			110° C.			230° C.		
		5,000.	10,000.	14,000.	5,000.	10,000.	14,000.	5,000.	10,000.	14,000.
		Damping Capacity, %.								
Ferrite—										
Armco iron	As received	3.08	4.10	4.11	3.60	4.62	4.75	4.06	5.07	5.23
Pearlite—										
0.9% carbon ...	As received	1.06	1.37	1.63	2.14	2.50	2.74	2.26	2.71	2.94
Martensite—										
0.9% carbon ...	W.Q. 780° C.....	1.32	1.50	1.60	1.52	1.71	1.82	2.06	2.25	2.29
Troostite—										
0.9% carbon ...	W.Q. 780° C., T. 270° C.†	1.34	1.51	1.57	0.92	1.08	1.18	1.51	1.67	1.75
0.9% carbon ...	W.Q. 780° C., T. 400° C.	0.94	0.99	1.02	1.20*	1.20*	1.20*	2.22	2.26	2.25
0.3% carbon ...	O.Q. 860° C.	0.95	1.22	1.39	1.02	1.25	1.41	1.66	2.10	2.20
Sorbite—										
0.9% carbon ...	W.Q. 780° C., T. 500° C.	0.89	0.95	0.96	1.12	1.16	1.16	2.10	2.27	2.26
0.3% carbon ...	W.Q. 850° C., T. 675° C.	0.90	1.66	2.16	0.78*	1.56*	2.01*	—	—	—

* Estimated. † From unpublished curves.

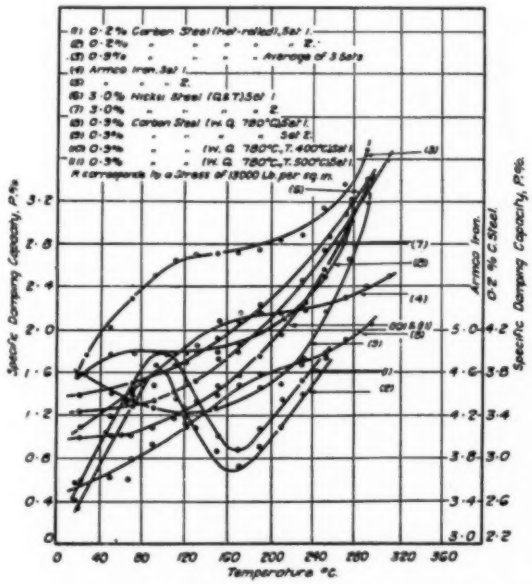

Specific Damping Capacity, P %
Armco Iron.
0·2 % C Steel
Specific Damping Capacity, P %
Temperature °C.
0 40 80 120 160 200 240 280 320 360
3·2 2·8 2·4 2·0 1·6 1·2 0·8 0·4 0
5·0 4·2 4·6 3·8 4·2 3·4 3·8 3·0 3·4 2·6 3·0 2·2

Fig. 3.—Curves showing effect of temperature on damping capacity.

The general effect of temperature, as is shown in Fig. 3, is to increase the damping capacity, although the curves are not always continuous and regular. Particularly is this the case with the 0·2% carbon steel. At temperatures of the order of 250–310° C. there is—except in the cases of the Armco iron and the sorbitic nickel steel—a relatively sudden and enormous rise in the damping value. Both composition and structure would appear to affect this phenomenon, but beyond the general statement that materials which are normally hard show the effect at a rather higher temperature than do softer ones, no useful generalisation can be made.

It has usually been found to be the case that the damping-capacity determinations on a second or subsequent series of tests are lower than those given by the first. A possible explanation of this may be found in the fact that during the first run the sample has been heated to temperatures within the "blue-brittle" range. It is of significance perhaps that this difference was greatest in the case of Armco iron.

This research was commenced in the hope of obtaining another method of investigating the "low"-temperature change-points in iron and steel. Although it is shown that these changes are not without their influence on the damping properties, it is clear that this method is, in general, unsuited to the subject under examination. At the same time, and especially in the cases of the 0·2 and the 0·9% carbon steels, as Table IV shows, there are points of such obvious similarity between the present results and those of Goffey and Thompson[4] for the torsional limits of proportionality of electrolytic iron and 1·0% carbon steels, that a common underlying cause can hardly be doubted.

TABLE IV.

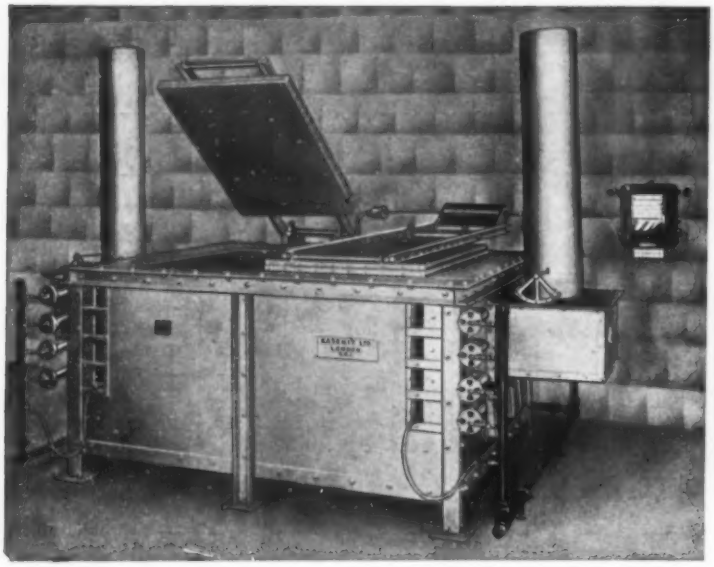
COMPARISON OF THE POINTS OF INFLEXION IN THE DAMPING CAPACITY CURVES AND THE TORSIONAL LIMITS OF PROPORTIONALITY OF TWO CARBON STEELS.

Material.	Carbon, 0.2%.			Carbon, 0.9%.		
Temperature	90° C.	170° C.	270° C.	120° C.	190° C.	310° C.
Damping.	Max.	Min.	Sudden increase of P.	Change of direction.	Change of direction.	Sudden increase of P.
Limit of Proportionality.	Max.	Max.	Min.	Min.	Max.	Max.

4 Goffey and Thompson: *Journal of the Iron and Steel Institute*. 1923. No. I. p. 465.

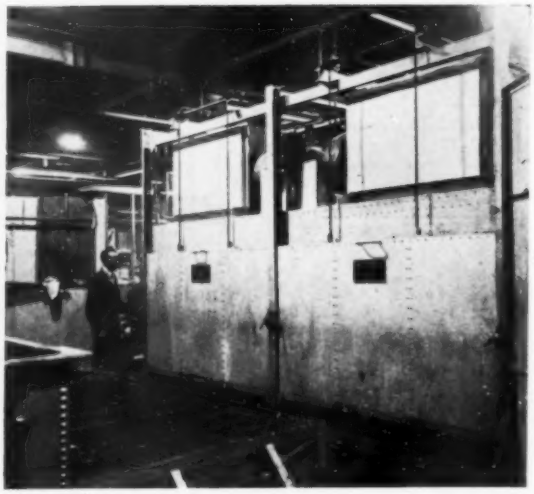
Fritted Powder Workpieces

THE final sintering of pressed articles made from metal powders, such as tungsten turning tools, has been carried out in the past by heating at about 1,500° C. in a hydrogen atmosphere to avoid oxidation. A more recent proposal involves ignition of the pressed workpiece in a carbon-monoxide atmosphere while exposed to the high temperature developed by a high-frequency electric field. In the manufacture of a tungsten-cobalt conical turning tool (92% tungsten : 8% cobalt) the more or less compactly pressed cone (made from the metal powder mixture) is placed on a support of porcelain and pushed into a porcelain cylinder through which a carbon-monoxide-containing gas is circulated while the temperature is gradually raised to 1,150° C. in the high-frequency field generated from a coil. A carburizing effect is produced as part of the carbon-monoxide decomposes. The considerable shrinkage, sometimes amounting to 30%, makes for great toughness of the sintered tool. This treatment is particularly beneficial in the production of tools from tungsten, titanium and boron powders. Bronze powder pressings can be sintered by this process at much lower temperatures—e.g., bronze bushings can be made at as low as 700° C. (Swiss Pat. 207,105).



Courtesy of Kasenit, Ltd.

Fig. 14.—Natural draught salt-bath furnace for light alloys.



Courtesy of Controlled Heat and Air, Ltd.

Fig. 16.—A gas-fired air-circulated double compartment shelf loading light alloy ageing oven.

Some Recent Heat Treatment Furnace Installations

(*Continued from page 33*)

installed mention may be made of two electrically-heated pit furnaces by Siemens Schuckert (Gt. Britain) Ltd. have been recently installed at a large works for annealing, solution and precipitation treatment, which may be used at temperatures up to 550° C. The useful dimensions of the work basket are 6 ft. 9 in. diameter and 9 ft. deep. An important feature of these furnaces is the powerful air circulation system, which is claimed to give temperature accuracy throughout the charge of the order of ± 2° C.

The precipitation treatment of light alloys is largely dependent for its success on the maintenance of a uniform temperature of the components treated. The temperature is dependent upon the alloys used and the soaking period will vary with the sectional size of the parts treated, the heating equipment, therefore, must be flexible. For this purpose a diffused circulation system of heating has been evolved, which is claimed to ensure uniform oven temperature in all parts of the working space for any condition of loading and working temperature. A gas-fired furnace of this type is shown in Fig. 16, and, in recent tests, eight thermo-couples were distributed over the whole batch of work; the total variation did not exceed 2° C. An additional feature of this system is that while heavy loads can be brought to the required temperature very quickly, without overheating any part of the work, by automatic control of combustion conditions the gas consumption during the soaking period is kept at a minimum.

Fig. 15.—Very large salt baths installed for the treatment of light alloy sheet and presswork.

Courtesy of Incandescent Heat Co., Ltd.

Modern Trends in the Manufacture of Magnesium and its Alloys

OF the natural raw material savailable for magnesium production the most important are the carbonates, magnesite and dolomite, and the double salt, carnallite. Some progress has also been made in the utilisation of magnesium chloride-containing brines*. Direct reduction of magnesia, the process of maximum chemical simplicity, has proved extremely difficult to adapt to technical conditions and is not yet a practical proposition.

Reducing agents employed in the thermal processes, in addition to calcium carbide and aluminium, now include carbon and silicon, the latter in the form of ferro-silicon. Energy consumption in reduction with ferro-silicon is about 20 kilowatt hours per kilogram of magnesium or the same as in the electrolysis of fused anhydrous magnesium chloride. The latter process, however, is still responsible for the greater part of the output of magnesium at the present day with electrolysis of carnallite taking a secondary place. Complete drying of magnesium chloride is a very difficult matter and has compelled the industry to go over for the most part to the chlorination of magnesite or magnesia. In the course of the subsequent electrolysis the reaction is so conducted as to release the chlorine in the anode chambers in a sufficiently high concentration to permit it to be immediately returned to the cycle for production of fresh anhydrous magnesium chloride.

Methods have been evolved for the elimination from the crude metal of impurities such as nitrides, oxides and chlorides and especially of other metals like iron, a field in which Dr. A. Beck and his collaborators have been prominent. The removal of these foreign substances is indispensable for the attainment of the desired degree of corrosion resistance by magnesium alloys. In the moulding department the production of large and complicated parts in sand moulds has been rendered possible by the addition to the moulding sand of protective agents like sulphur and boric acid. Single crystal research has been of the greatest service in clarifying the nature of plastic deformation and thus determining the factors which make magnesium less easily subject to plastic deformation than other metals. The practical sequel to these investigations has been the introduction into the industry of hydraulic presses up to a total pressure of 15,000 tons.

(From report of a lecture by Dr. A. Beck in *Chemiker-Zeitung*, February 28, 1940.)

*METALLURGIA, **21**, 1940, P. 170.

"Elektron" forgings are finding ever-increasing use in a wide range of industries today because of the lightness, strength, good fatigue properties and exceptional ease of machining for which they are noteworthy, and because they can be forged to exceptionally fine limits. Our illustration shows a selection of components, indicating to some degree the intricacy which may easily be achieved, and the perfection of the finish. Even better examples are actually in routine production but for obvious reasons we are not permitted to show them. Full co-operation in the production of "Elektron" forgings together with a wealth of technical data is freely at the service of engineers and designers. *"Elektron" is the only constructional light metal produced from British ores.*

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0.1% proof stress	12 tons per square inch.
Maximum stress	20 tons per square inch.
Elongation	12% to 15%.
Fatigue range	±8.9-9.0 tons per square in. (20 *million reversals*).

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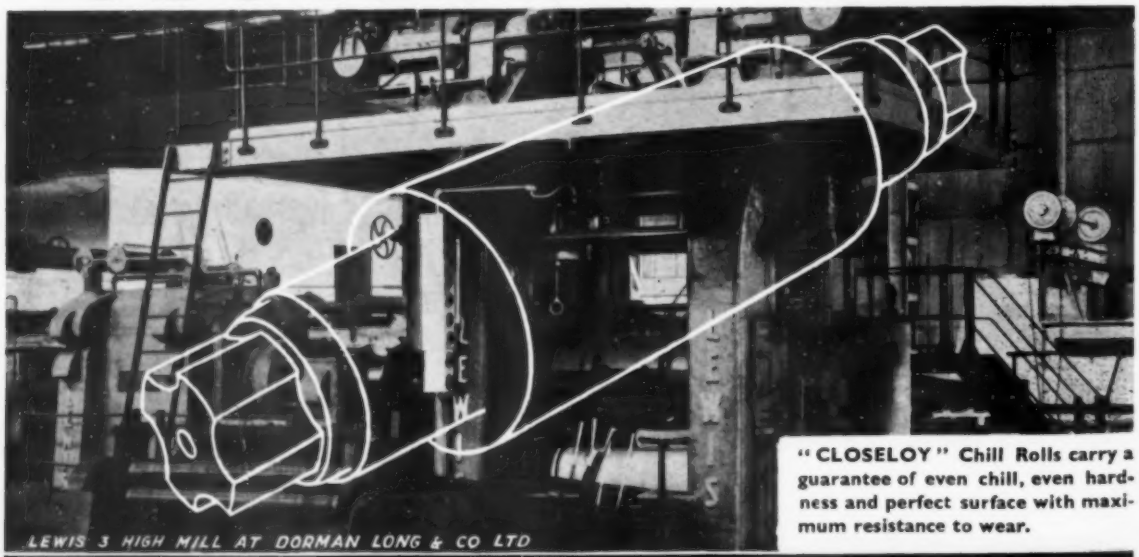

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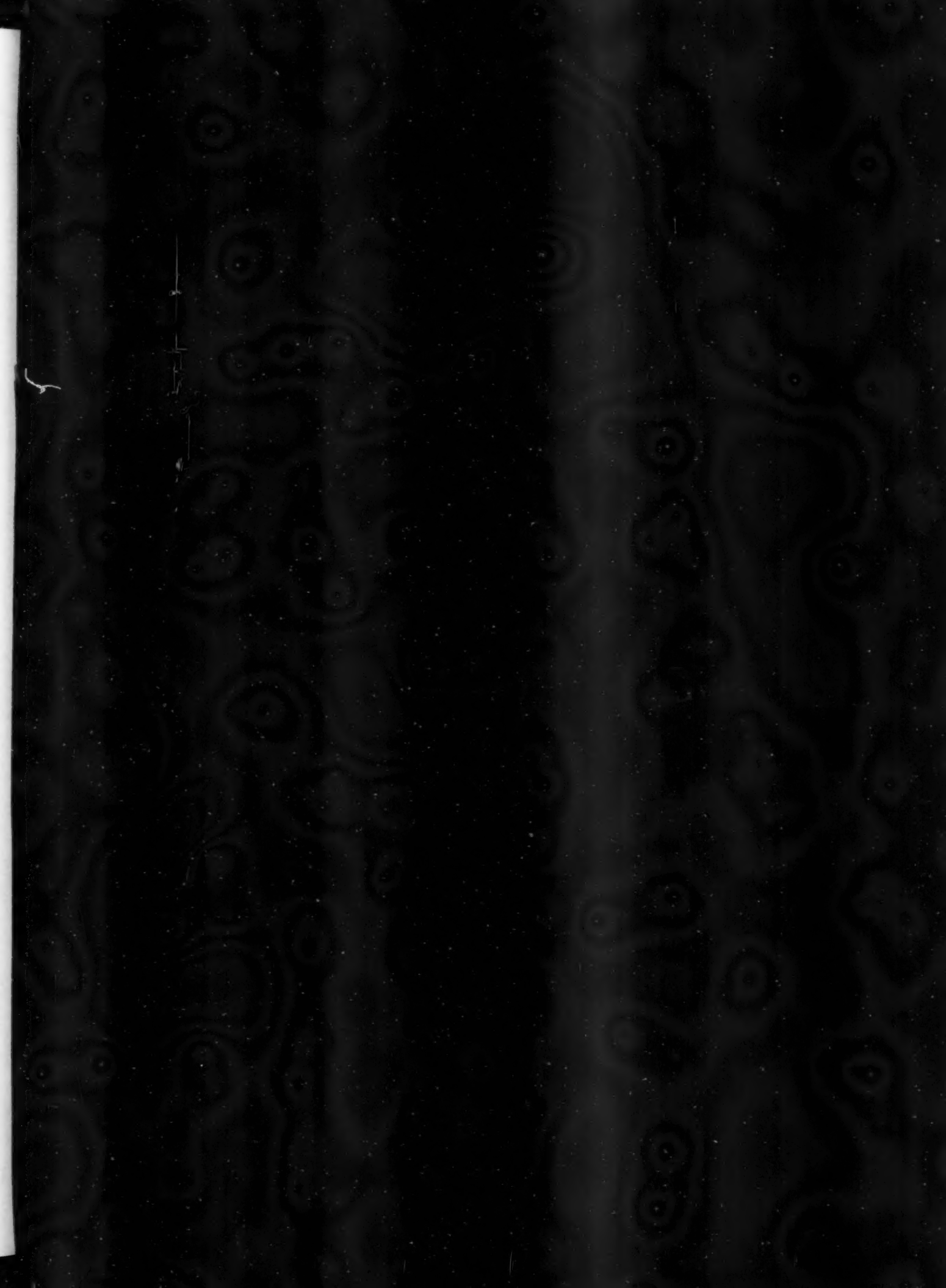
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